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SPACELAB USER IMPLEMENTATION ASSESSMENT STUDY

(SOFTWARE REQUIREMENTS ANALYSIS)

VOLUME II

TECHNICAL REPORT

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for
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FOREWORD

The Software Requirements Analysis Study was conducted to definitize requirements and implementation approaches for the Advanced Technology Laboratory (ATL) Spacelab payloads of Langley Research Center. The effort consisted of an expansion and in-depth analysis of ATL software requirements identified in the basic study, *Spacelab User Implementation Assessment Study*. The study was conducted by the Space Division of Rockwell International Corporation under Contract NAS1-12933. Mr. F. O. Allamby was the technical manager for the Langley Research Center.

The final report consists of two volumes: an executive summary, and a technical report of all the analyses/trades conducted during the course of the study. A succinct summary of the study objectives, principal conclusions, tradeoffs, recommendations, and future related efforts is presented in the executive summary. The technical report includes the development of the study data base, synthesis of implementation approaches for software required by both mandatory on-board computer services and command/control functions, and identification and implementation of software for ground processing activities.

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1.0 INTRODUCTION

This report covers the engineering analyses and evaluation studies conducted for NASA-Langley Research Center as an extension of the Spacelab User Implementation Assessment Study (SUIAS). This extension, the Software Requirements Analysis, relates to Advanced Technology Laboratories in particular and to all Spacelab users in general. In a concurrent study (Cost Reduction Alternatives), Task 1 (On-Board Computer Utilization and Software Integration) interacted and contributed to the concepts examined here.

1.1 STUDY BACKGROUND

The tasks of the basic SUIAS definitized alternate integration and checkout approaches for ATL Spacelab payloads. One of the more significant factors in the processing cycle that would affect the costs and efficiency of the activities was the software required by the experiment systems and the ground operations. Not only could software and the approach to developing/validating software become the pacing items in the processing cycle, but these two items could also become a significant cost factor. In addition, these items could directly impact principal investigator (PI) access/participation and experiment system development costs. Thus, a more detailed assessment and programmatic evaluation of software requirements, implementation and integration were required. The definitization of the Orbiter and Spacelab information management/data processing/computer systems permits a detailed evaluation of ATL software requirements and implementation approaches that are compatible with the cost-effective integration and checkout concepts that were derived in the basic SUIAS tasks. Where appropriate, modifications to the SUIAS concepts are incorporated to reflect ATL programmatic savings that result from the software definition.

The primary objective of this effort was to develop an integrated approach to guide the development of all software that is *required* to efficiently/cost effectively support the ATL flight and ground operations. A corollary to this objective was to derive criteria for inclusion of software in the experiment system definition. Software, in the context of this study, is not limited to computer programming; it also encompasses the procedures by which a task is accomplished. A task was defined to be a manually directed sequence of actions, such as the proper order of switch closures to unlock, erect and point an antenna. Every integration task or activity is to be accomplished by a consistent procedure, which may include a computer facility if the benefits so obtained outweigh the costs.

A principal criterion in the development of the software definition is to develop an approach that will maximize the autonomy of each experiment and define each experiment system as self-contained as is possible. The intent of this criterion is to gain flexibility in both flight and ground operations by avoiding the necessity for development of an interdependent experiment/experiment, experiment/Spacelab, or experiment/Orbiter hardware systems. Independence of experiment systems is a goal that would be limited only by factors externally imposed;

dependence upon Spacelab and Orbiter support systems would be limited to those *housekeeping* services that are standard, readily-available provisions of these two program elements.

A second criterion in the development of the software definition is to derive an approach to flight and ground operations that will enhance/promote the usability of the ATL Spacelab to diverse PI's. The approach must reflect direct access and involvement of the PI's in an understandable format. The approach must standardize the techniques for PI participation and avoid unnecessary interactions with other program elements. The selected procedures should separate the PI's responsibilities, clearly and unambiguously, from those of the payload integrator and Spacelab/Orbiter operators. Unavoidable interactions would be established by standard-format documentation and procedures rather than unique/rigid specifications.

1.2 STUDY APPROACH

The approach used in this study is illustrated in Figure 1.2-1.

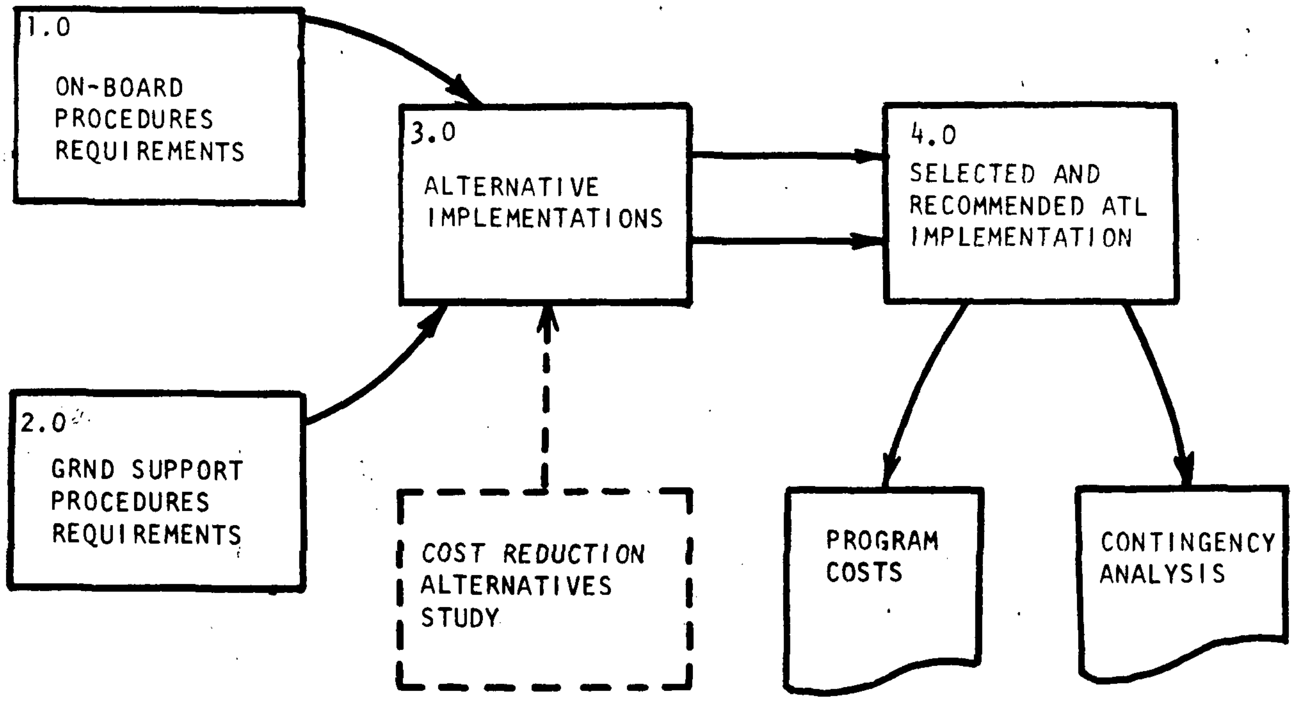


Figure 1.2-1. Study Approach

The Software Requirements Analysis (SRA) was divided into four task areas: (1) identification of the essential on-board inflight procedures; (2) identification of essential ground support procedures; (3) synthesis and evaluation of alternative implementation of essential procedures; and (4) selection of the preferred approach including criteria and rationale for selection, and definition of hardware and software development requirements.

Task 1 was conducted by first identifying the on-board functions that were essential to the individual experiment in-flight operations. Twenty-seven automated on-board computer services, ranging from digital data acquisition to complex mathematical operations, were identified. The experiment designer determined which of those services (or functions) were needed to set up, calibrate, operate, monitor, control, or support his experiment.

A parallel study, Cost Reduction Alternatives (CRAS), performed by Rockwell for NASA-Langley, evaluated different approaches to implement the identified on-board computer services, ranging from maximum centralization using the Spacelab control and data management subsystem (CDMS) experiment processor to maximum decentralization using commercially available mini/micro processor elements. A micro-processor is a *computer on a chip*, a recent development, and is usually *built in* the equipment that requires a service. Mini-processors use the same elements, but are considered to be *stand-alone* devices and would provide several services simultaneously.

The results of the CRAS clearly indicated that an approach that implemented the required on-board computerized services by using dedicated (to that experiment) mini/micro processors had advantages of lesser cost, more convenience to the PI, and greater flexibility in adapting the processing elements (both hardware and software) to the experiment requirements. A micro-processor would be assigned for a single function, such as sensor pointing control, and a mini-processor would be assigned for integrated process control of each experiment. The CDMS processor would be assigned only those functions that represented the single interface between Spacelab and the Orbiter avionics. This preferred approach was incorporated in this analysis without further justification.

Task 2 was approached in a manner similar to Task 1. Ground support for this study includes the procedures used by the mission integration staff to plan, design, develop, and conduct an ATL mission. Both technical and administrative procedures are included. As in Task 1, some of these procedures are necessarily automated with some computer--the calculation of a ground track, for example. Other procedures might be manual at first, but with increasing flight rates they would be accomplished more efficiently with computerized supp.

In Task 3, after identification of the mandatory on-board computer services, there remain those which relate directly to the operator's means of monitoring and controling the experiment--command and control. The command and control function requires some means of displaying information for evaluation, and some means of changing the experiment configuration or operating mode--a control/display panel--and the computer services to acquire, format, and generate the displays; and sense, transmit, and decode switch closures or their equivalent. The requirements for command and control (to set up, calibrate, operate, monitor and control the experiment) were identified by developing the step-by-step actions of the operator, using a hardwired control/display panel. For comparative evaluation, these same actions were mechanized using an *intelligent terminal* (a CRT display and a keyboard), and determining the additional hardware and software required for this implementation. Evaluation criteria included time of response, confidence and cost. Also, in Task 3, implementation alternatives for the ground support procedures considered available facilities and computer programs; evaluation criteria included time of response, cost, and availability.

Task 4 integrated the previous alternatives into a set of compatible procedures for both in-flight and ground processing requirements, incorporating the dedicated mini/micro computer approach. Selection rationale for automation and/or integration are developed, followed by definitization of the hardware and software development requirements. A review of the basic SUIAS, and the impact on it by the recommendations of this study, is included.

The study results are presented in the following sections, beginning with the development of a data base to establish the on-board processing requirements (Section 2.0). Section 3.0 analyzes the required on-board services for the reference ATL payloads, and develops the cost factors pertinent to implementation, following the methodology and recommendations derived in the Cost Reduction Alternatives Study. Section 4.0 emphasizes the command and control functions and derives cost factors for three approaches --hardwired, computer-aided, automated.

Section 5.0 is devoted to establishing a data base for the ground processing requirements, based upon the original SUIAS. Alternative means of implementing the ground processing services are evaluated in Section 6.0, and cost factors are developed.

Section 7.0 assembles the several cost factors of an ATL programmatic basis for three traffic models, and includes a contingency analysis and recommendations for further effort. The specific implications of the pallet-only configuration on software requirements are discussed in Section 8.0. In Section 9.0, a succinct summary of the results that affect the PI and should be used in the development of experiment systems is presented. In the Appendix are assembled the hardware and software descriptive data that were used to develop the cost factors and implementation approaches evaluated in this study.

2.0 ON-BOARD PROCESSING REQUIREMENTS DATA BASE

In order to assess the potential use of computers and software to support the on-board experiment operations, a definitive set of data for each representative ATL payload was required. The data contained in TM X-2813, *Study of Shuttle-Compatible Advanced Technology Laboratory* (Langley, September 1973), and the *Shuttle Sortie Payload Description* study (MSFC) were expanded by Rockwell specialists to provide the appropriate depth of experiment mechanization.

The ATL experiments used in this analysis were grouped into three representative payloads (Table 2.0-1). Three of the 28 experiments included in the basic SUIAS were deleted by Langley from this analysis (PH-1, Wake Dynamics; PH-5, Radiation Environment; and EN-2, Material Fatigue). The 25 remaining experiments were used to create the on-board processing requirements data base. Note that some experiments are assigned to 2 or 3 payloads; it was for this reason that the data base was constructed on an individual experiment basis, which could then be assembled in a variety of groupings.

The 25 experiments identified as complements of the ATL missions were defined by preparing a set of descriptive documents after reviewing available reports (i.e., TM X-2813). These documents were reviewed with resident and NASA consultants to verify that they represented the current state of development at this time (June 1975). Each descriptive *data pack* was constructed without a preconceived approach to integration, as what could be called a laboratory mechanization; that is, the experiment was complete in itself, including data system components and manual control and display components.

There were two reasons for this approach:

1. This is how the PI would conceive, assemble and test a breadboard experiment system, and is the way he could best describe it.

2. When the several experiments are integrated into a payload the *mix* is highly variable, and necessary compromises may change with each specific payload. By starting from a common basis, the payload integration designer has more flexibility to produce an optimum mission.

The basic data packs consisted of the following documents: (1) a narrative description identifying the purpose, the sensors, and the approach; (2) an equipment list identifying the experiment system components by name and location; (3) an equipment performance description containing short paragraphs identifying each component and what it does; (4) a signal flow diagram showing the command and data paths between the components; (5) a measurement list identifying the data form, rate, source and destination; (6) a control list identifying the actions, form, and source; and (7) an experiment data management requirements matrix. Samples of these documents are shown in Figures 2.0-1 through 2.0-7.

Table 2.0-1. ATL Experiment Definition and Payload Groupings

EXPERIMENT IDENTIFICATION		EXPERIMENT SSPDA NO.	PAYLOAD 1 MODULE + PALLET	PAYLOAD 2 MODULE + PALLET	PAYLOAD 3 PALLET-ONLY
NAVIGATION					
NV-1	MICROWAVE INTERFEROMETER	XST-001			X
NV-2	AUTONOMOUS NAVIGATION	XST-004			X
NV-3	MULTIPATH MEASUREMENTS	XST-007	X		
EARTH OBSERVATIONS					
EO-1	LIDAR MEASUREMENTS	XST-010			X
EO-2	TUNABLE LASERS	XST-011	X		
EO-3	MULTISPECTRAL SCANNER	XST-012		X	
EO-4	RADIOMETER	XST-002			X
EO-5	LASER RANGING	XST-003	X		
EO-6	MICROWAVE ALTIMETRY	XST-005		X	
EO-7	SEARCH AND RESCUE AIDS	XST-006			X
EO-8	IMAGING RADAR	XST-008			X
EO-9	RF NOISE	XST-009	X		
PHYSICS AND CHEMISTRY					
PH-2	BARIUM CLOUD RELEASE	XST-015	X		X
PH-3	AEROSOL PROPERTIES	XST-016	X	X	
PH-4	MOLECULAR BEAM LAB	XST-017	X		X
PH-6	METEOR SPECTROSCOPY	XST-019			X
MICROBIOLOGY					
MB-1	COLONY GROWTH	XST-020	X	X	
MB-2	MICRO-ORGANISM TRANSFER	XST-021		X	
MB-3	BIOCELL ELECT FIELD OPACITY	XST-022	X		
MB-4	BIOCELL ELECT CHARACTERISTICS	XST-023		X	
MB-5	BIOCELL PROPERTIES	XST-024		X	
ENVIRONMENTAL EFFECTS					
EN-1	MICRO-ORGANISM SAMPLING	XST-027	X	X	X
EN-3	NON-METALLIC MATERIALS DEGRAD	XST-029		X	X
COMPONENTS AND SYSTEMS					
CS-2	ZERO-G STEAM GENERATOR	XST-026		X	
CS-X	CONTAMINATION MONITOR	XST-040	X	X	X

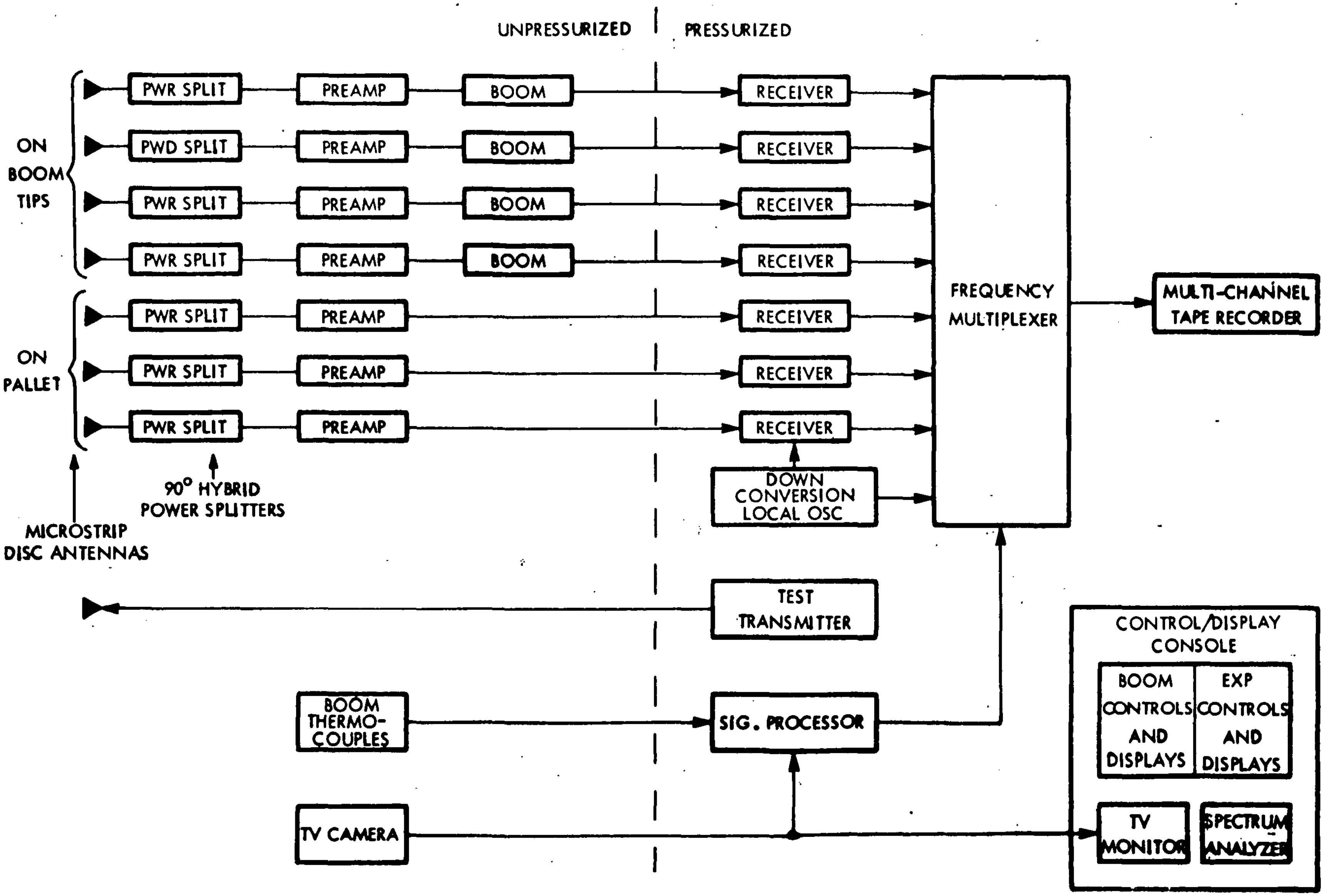


Figure 2.0-1. Typical Block Diagram - Microwave Interferometer (NV-1)

MICROWAVE INTERFEROMETER (NV-1)

SSPDA REF. NO.	COMPONENT	QUANTITY	LOCATION REQUIREMENT	ASSEMBLY LOCATION
-	DISC ANTENNA	7	UNPRESSURIZED	EXT. BOOMS
-	POWER SPLITTER	7	UNPRESSURIZED	EXT. BOOMS
ST-002	PREAMPLIFIER	7	UNPRESSURIZED	EXT. BOOMS
-	THERMOCOUPLE	16	UNPRESSURIZED	EXT. BOOMS
-	BOOM MOUNT (PEDESTAL)*	1	UNPRESSURIZED	PALLET
ST-003	EXTENDABLE BOOM	4	UNPRESSURIZED	PEDESTAL
ST-025	TV CAMERA	1	UNPRESSURIZED	PEDESTAL
ST-005	RECEIVER	7	PRESSURIZED	PEDESTAL
-	TEST TRANSMITTER	1	PRESSURIZED	PALLET
-	DOWN CONV. OSCILLATOR	1	PRESSURIZED	PALLET
ST-012	BOOM AND EXPERIMENT CONTROLS	1	PRESSURIZED	CONSOLE
ST-006	FREQUENCY MULTIPLEXER	1	PRESSURIZED	RACK
-	VIDEO RECORDER	1	PRESSURIZED	RACK
ST-007	SPECTRUM ANALYZER	1	PRESSURIZED	CONSOLE
ST-026	TV MONITOR	1	PRESSURIZED	CONSOLE
-	SIGNAL PROCESSOR	1	PRESSURIZED	CONSOLE
ST-020	D&C CONSOLE	1	PRESSURIZED	RACK

*SSPDA VERSION MODIFIED AND REDUCED IN WEIGHT.

Figure 2.0-2. Typical Equipment List

Space Division
Rockwell International

ANTENNA/BOOM ASSEMBLY

- DEPLOY, RETRACT & STOW 4 EXTENDABLE BOOMS; SUPPORT 7 MICROSTRIP DISC ANTENNAS, SEVEN 90-DEG HYBRID POWER SPLITTERS, & 7 PREAMPLIFIERS; SUPPORT TV CAMERA & TARGET LIGHT(S); SUPPORT TEST TRANSMITTER ANTENNA; & ACCOMMODATE 16 THERMOCOUPLES.

RECEIVERS

- INPUT 1.6 GHz (7 SIGNALS); DOWN-CONVERT EACH TO 3.0 MHz WITH 140 kHz OF DATA BANDWIDTH PER CHANNEL (7 CHANNELS).

RECORDER

1-TRACK VIDEO (TV); 1-TRACK MULTIPLEXER OUTPUT, ORBITER ANNOTATION & ENGINEERING DATA.

CONTROL & DISPLAY CONSOLE

- PROVIDE OPERATOR MANUAL CONTROLS & ENGINEERING DATA DISPLAYS; PROVIDE LABORATORY SPECTRUM ANALYZER TO SAMPLE INDIVIDUAL RECEIVER OUTPUTS & FREQUENCY MULTIPLEXER INPUTS & OUTPUTS; PROVIDE TV MONITOR WITH RETICLES TO DETERMINE BOOM DISTORTION/MOTION; PROVIDE TEST & ADJUSTMENT CONTROLS FOR PREAMPLIFIERS & AMPLIFIERS, TEST TRANSMITTER & TAPE RECORDER MODE-SELECT; PROVIDE ON/OFF & ADJUSTED CONTROL FOR TEST TRANSMITTER; SELECT TV DISPLAYS, TV CAMERA, & SIGNAL PROCESSOR OUTPUTS.

TEST TRANSMITTER

- PROVIDES 1.6 GHz LOW-POWER SIGNAL FREQUENCY MODULATED BY 10 kHz SIGNAL.

SIGNAL PROCESSOR

- ACCEPTS TEMPERATURE SENSOR OUTPUTS, TV SIGNAL & PROCESSOR DATA FOR DISPLAYS & INPUT TO FREQUENCY MULTIPLEXER.

FREQUENCY MULTIPLEXER

- ACCEPTS DATA FROM RECEIVERS & SIGNAL PROCESSOR FOR MULTIPLEXING INPUTS TO RECORDER.

Figure 2.0-3. Typical Equipment Performance Description - Microwave Interferometer (NV-1)

Space Division
Rockwell International

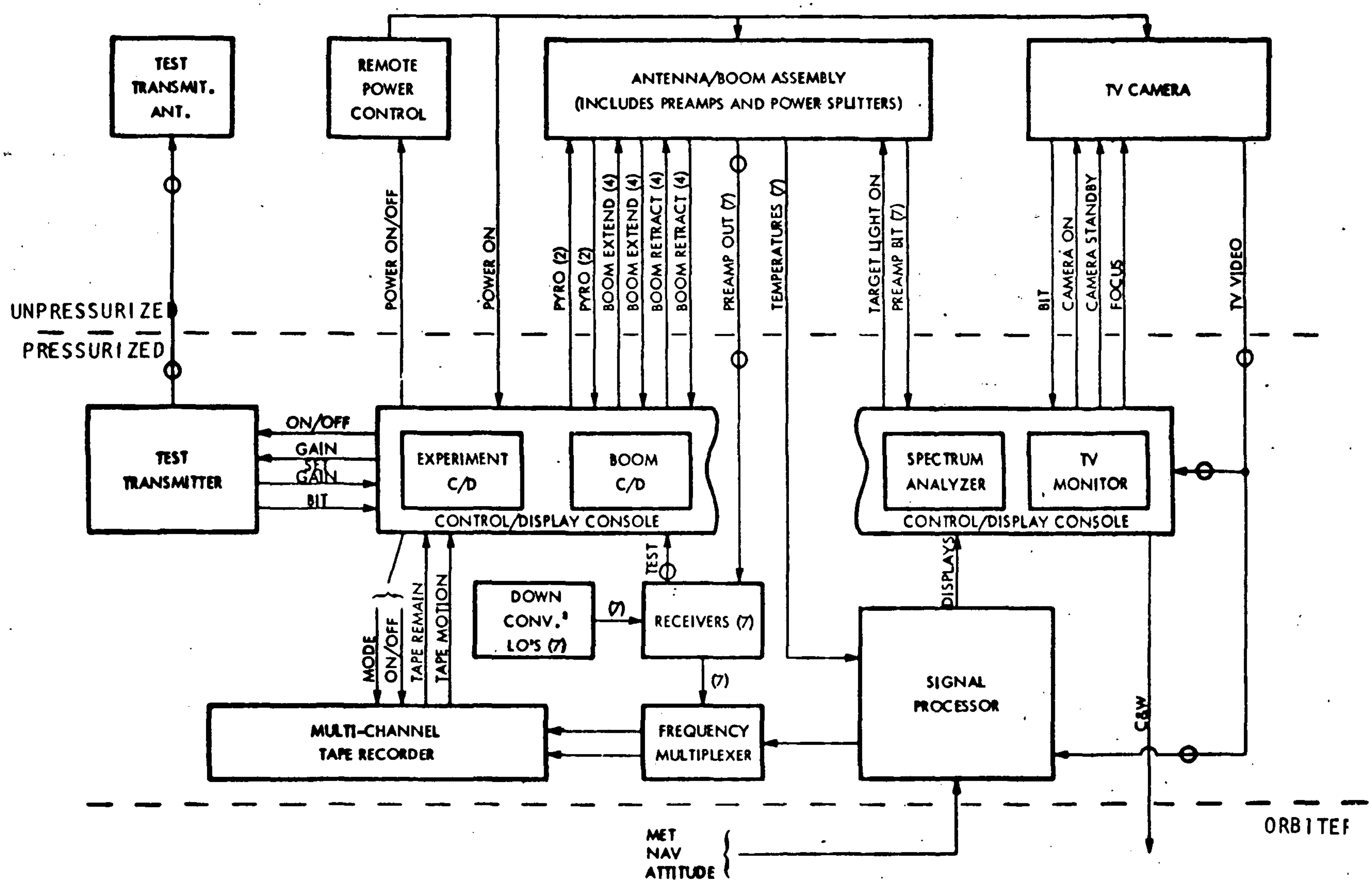
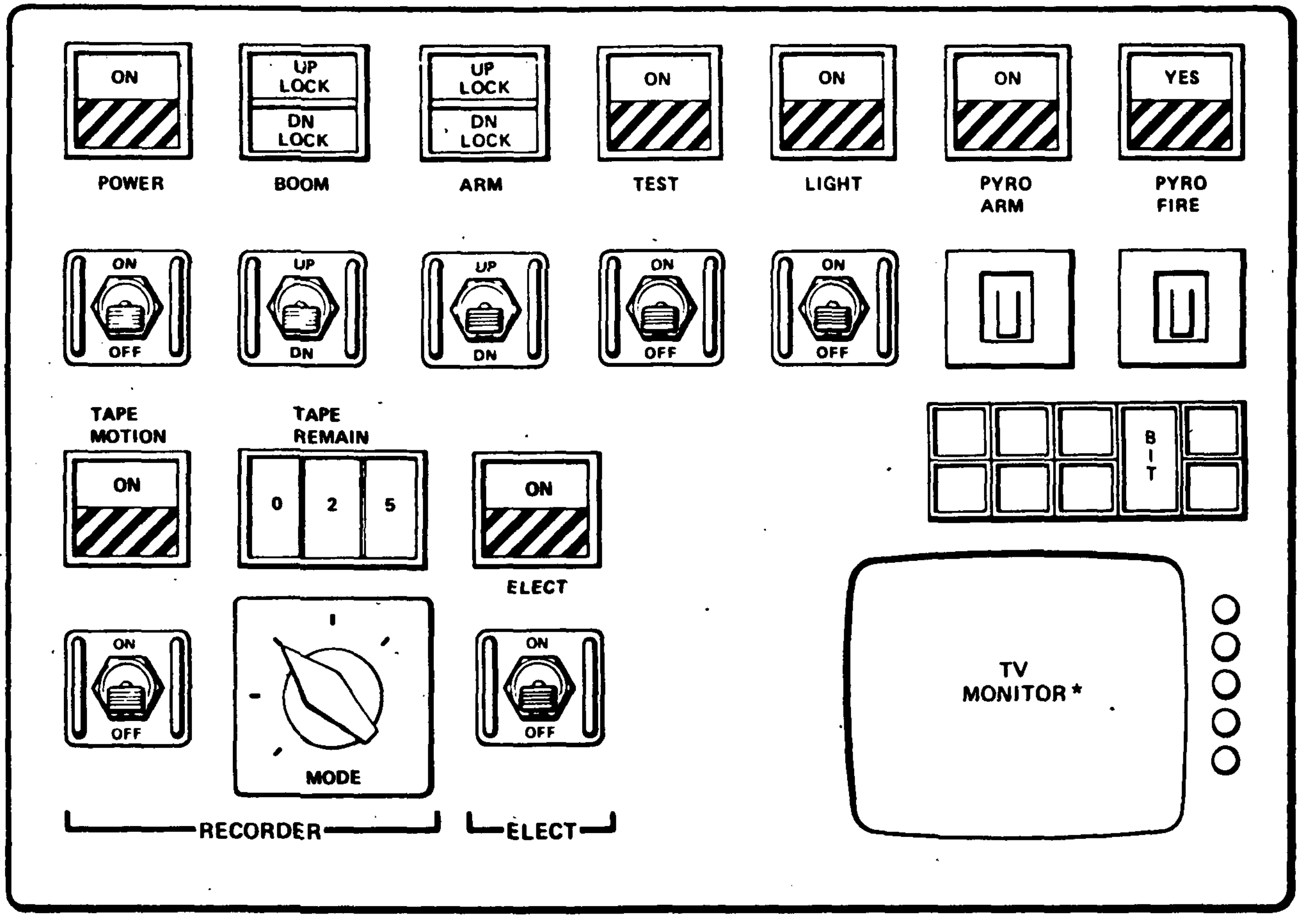


Figure 2.0-4. Typical Signal Flow Diagram - Microwave Interferometer (NV-1)

MICROWAVE INTERFEROMETER (NV-1)



*Not drawn to scale

Figure 2.0-5. Functional Control Panel (Hardwired)

MICROWAVE INTERFEROMETER (NV-1)

DATA RATE	739,200 bps
FRAME RATE	100 frames/second
FRAME SIZE	924 words/frame (8-bit words)
	7,392 bits/frame

(8-bit words)

Word 1	Sync	
Word 2	Sync	
Word 3	Sync	
Word 4	Sync	
Word 5	Frame Counter	
Word 6	Format I.D.	
Word 7	Bit Rate I.D.	
Word 8	Payload I.D.	
Word 9	Time 1	
Word 10	Time 2	
Word 11	Time 3	
Word 12	Time 4	
Word 13	Time 5	
Word 14	Cal. 1 RF channel 1 sample 1	Block 1
Word 15	Cal. 1 RF channel 1 sample 2	Block 1
Word 16	Cal. 1 RF channel 1 sample 3	Block 1
Word 17	Cal. 1 RF channel 1 sample 4	Block 1
⋮	⋮	⋮
Word 30	Cal. 1 RF channel 1 sample 17	Block 5
Word 31	Cal. 1 RF channel 1 sample 18	Block 5
Word 32	Cal. 1 RF channel 1 sample 19	Block 5
Word 33	Cal. 1 RF channel 1 sample 20	Block 5
⋮	⋮	⋮

(8-bit words)
(10-bit words)

Figure 2.0-6. Typical Measurement List

Space Division
Rockwell International

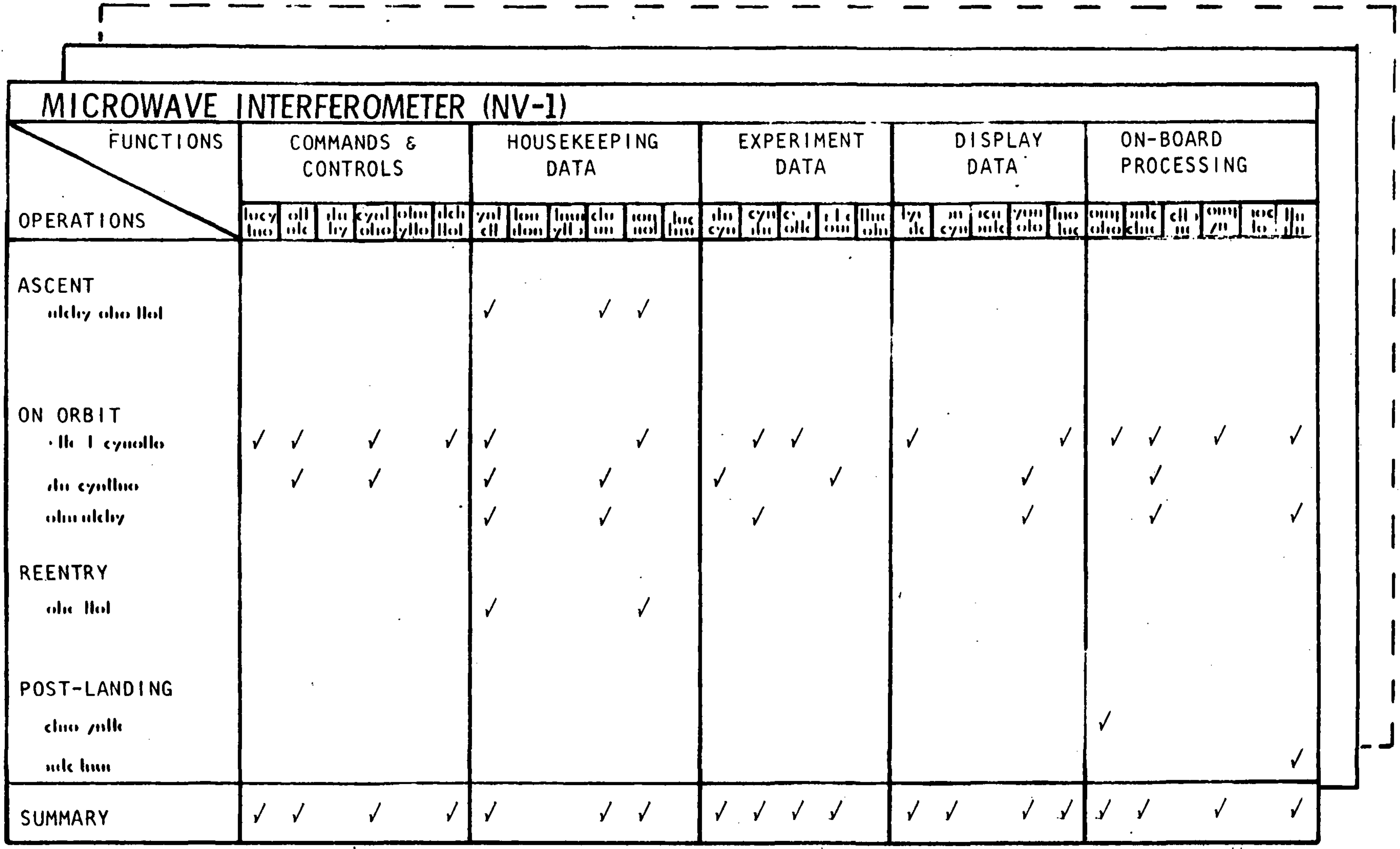
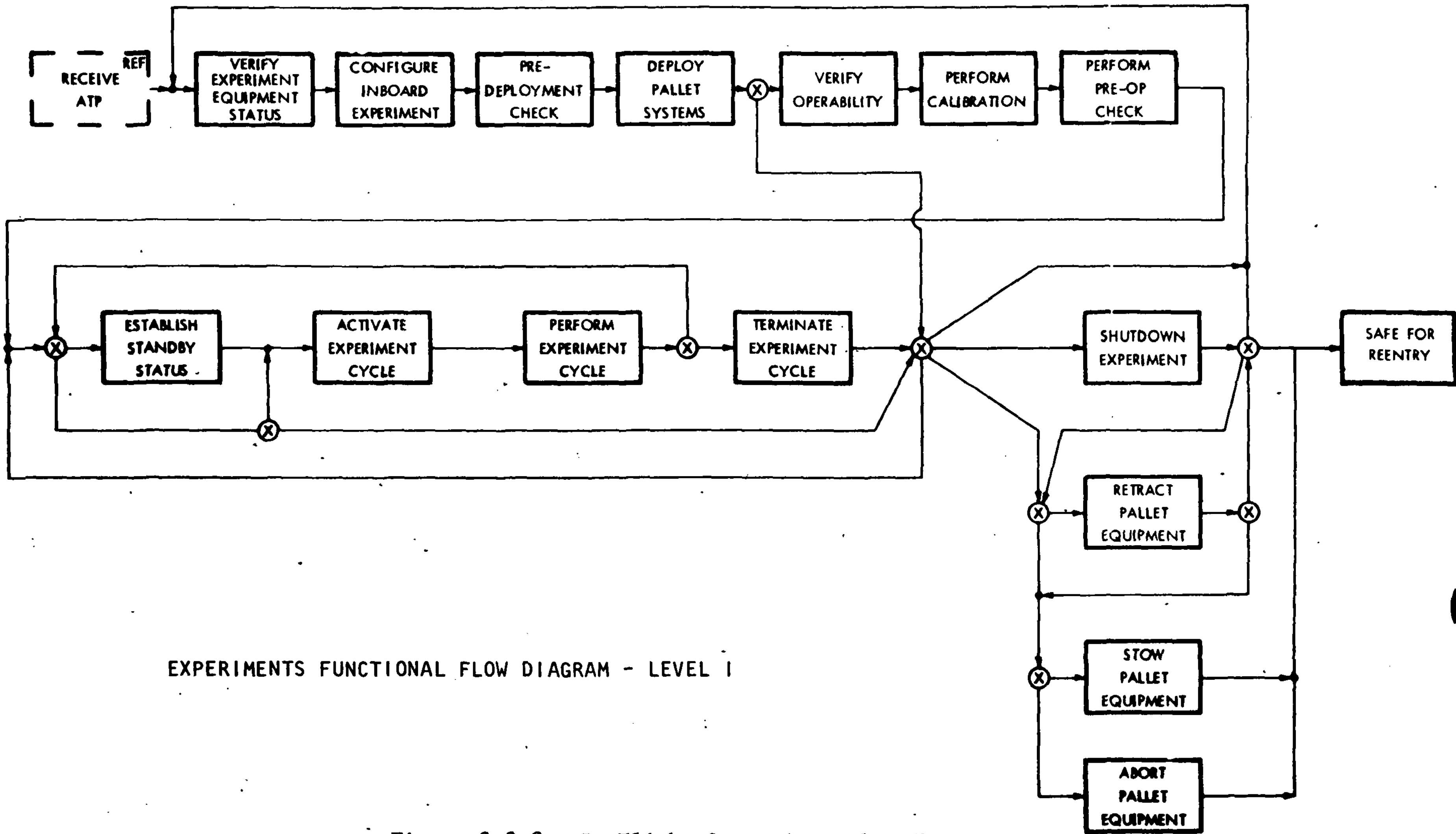


Figure 2.0-7. Experiment Data Management Requirements Matrix (Format Example)

Each experiment data pack contains most of these documents. The exceptions are certain *suitcase* experiments (i.e., the Microbiology group) where they are inappropriate. The assembled data packs were submitted to Langley in September 1975, and are not repeated here.

The documents are self-explanatory except for the experiment data management requirements (EDMR) matrix format illustrated in Figure 2.0-7. The EDMR format was constructed to illuminate the fact that different control operations and data system functions would be required throughout the various operational phases. Sixteen different operational phases in orbit (from initiation to final stowage) are identified in Figure 2.0-8 that require control and monitor from the Spacelab. Also, ascent and descent phases require control/monitor from the Orbiter. Appropriate detailed EDMR's and explanations of each phase were included in the data pack submittal.

The experiment operations flow chart (Figure 2.0-8) was generated to be applicable to all potential operations related to any experiment configuration. Each operation is defined as a unit package of activity with clearly defined start and stop conditions. Under ground laboratory conditions the several operations may flow smoothly in sequence; however, for an integrated payload which includes 10 to 12 experiments this may be impossible, and other experiments will require operator attention. By defining a number of breakpoints, where the sequence of activities for one experiment may be interrupted, allows the activities of several experiments to be combined into a total Spacelab operations timeline in a smooth and non-interfering manner.



EXPERIMENTS FUNCTIONAL FLOW DIAGRAM - LEVEL I

Figure 2.0-8. In-Flight Operations Flow Chart

3.0 ON-BOARD COMPUTER SERVICES

This section describes the methodology and implementation recommendations developed in the Cost Reduction Alternatives study (CRAS) and how they would apply to the three reference ATL payloads. Cost factors pertinent to this implementation are identified, and a model ATL payload was defined for assembling the programmatic cost estimates.

3.1 CRAS METHODOLOGY AND IMPLEMENTATION RECOMMENDATIONS

In CRAS, five representative Spacelab design reference missions were analyzed by creating an experiment definition data package for each experiment. The experiment data management requirements tabulations were reviewed by the Rockwell design engineering staff to identify the on-board computer services that were required. Twenty-seven services were identified, ranging from digital data acquisition to complex processing such as Fourier Analysis.

Each NASA principal investigator (PI) or the Rockwell specialist staff was consulted to determine, for each experiment, which of these on-board computer services were needed to support the in-flight operations of that experiment. The individual requirements were summarized on a payload basis, as shown in Figure 3.1-1.

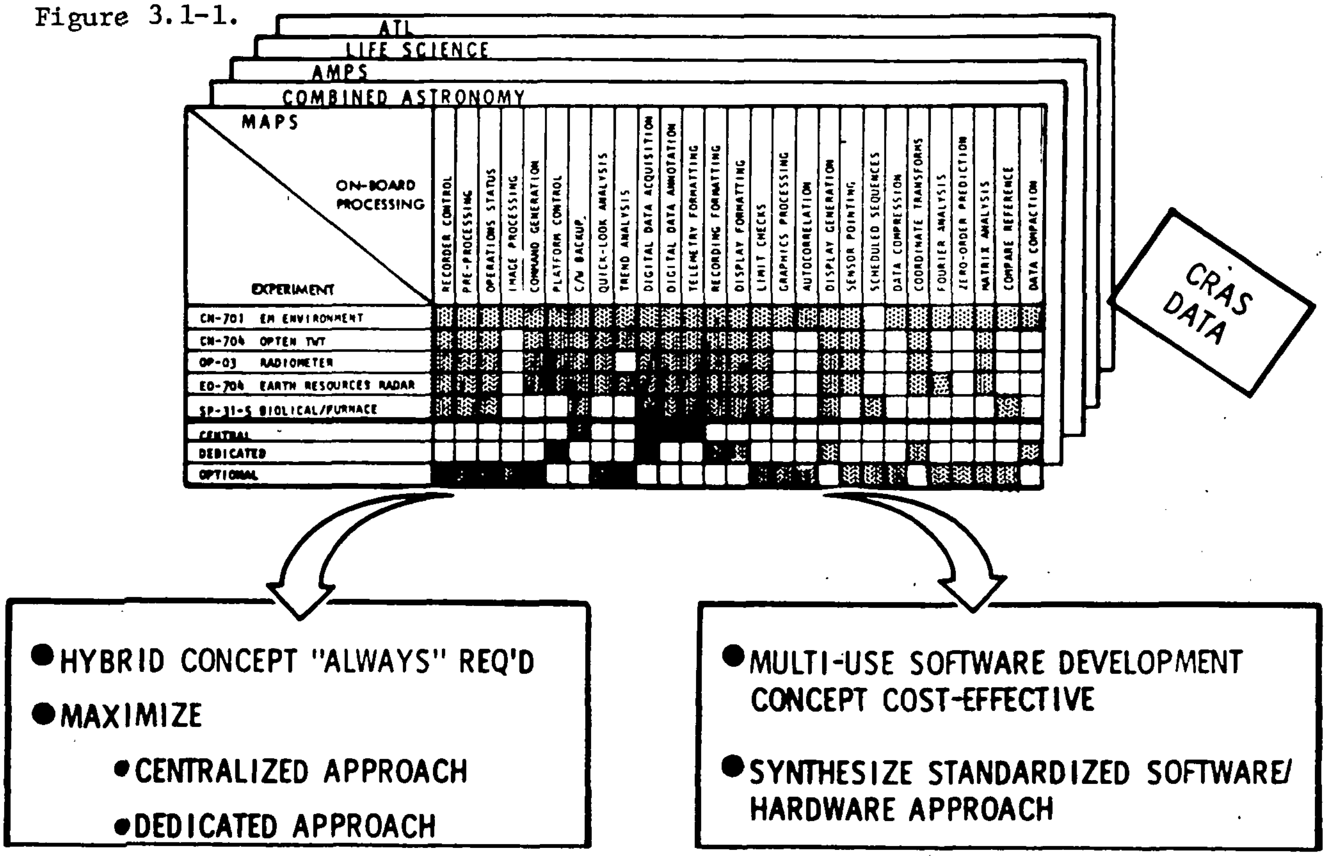


Figure 3.1-1. Identification and Analysis of On-Board Computer Services

The intent of the CRAS was to evaluate the most cost-effective implementation of these on-board computer services (1) by utilizing the Spacelab-provided control and data management subsystem (CDMS) experiment processor (termed the *centralized* approach), or (2) by utilizing experiment-provided commercially available mini/micro processors (termed the *dedicated* approach), or (3) some optimum hybrid combination of these two approaches.

The analyses indicated that it was impractical to have either an all-centralized approach or an all-dedicated processor approach. Some of the required services would have required computation rates or magnitudes that would absorb a disproportionately large share of the CDMS, and should therefore be performed by dedicated special processors. Alternatively, there is a constrained number of interfaces with the Orbiter avionics and it is not feasible to have multiple experiments connected without some centralized regulating (*traffic cop*) mechanism. Thus, a hybrid system was always required. The mechanization trade that was conducted was to compare hardware/software costs between a maximized centralized processor approach and a maximized dedicated processor approach.

One additional conclusion that was drawn from the analysis of the on-board services of the representative CRAS payloads was that these services were required by multiple experiments and multiple payloads. Thus, a cost-effective approach would be to maximize the reuse of software which, in turn, requires a degree of standardization of both hardware and software.

A software development concept (see Figure 3.1-2) was synthesized that would maximize the reuse of software. This concept consisted of a software development tool that was called the *flight software support system (FSSS)*. The FSSS contained a library of subroutines that corresponded to the mandatory on-board services identified for multiple experiments and payloads. The FSSS also included the software required to link these subroutines together to produce an experiment-specific flight application program.

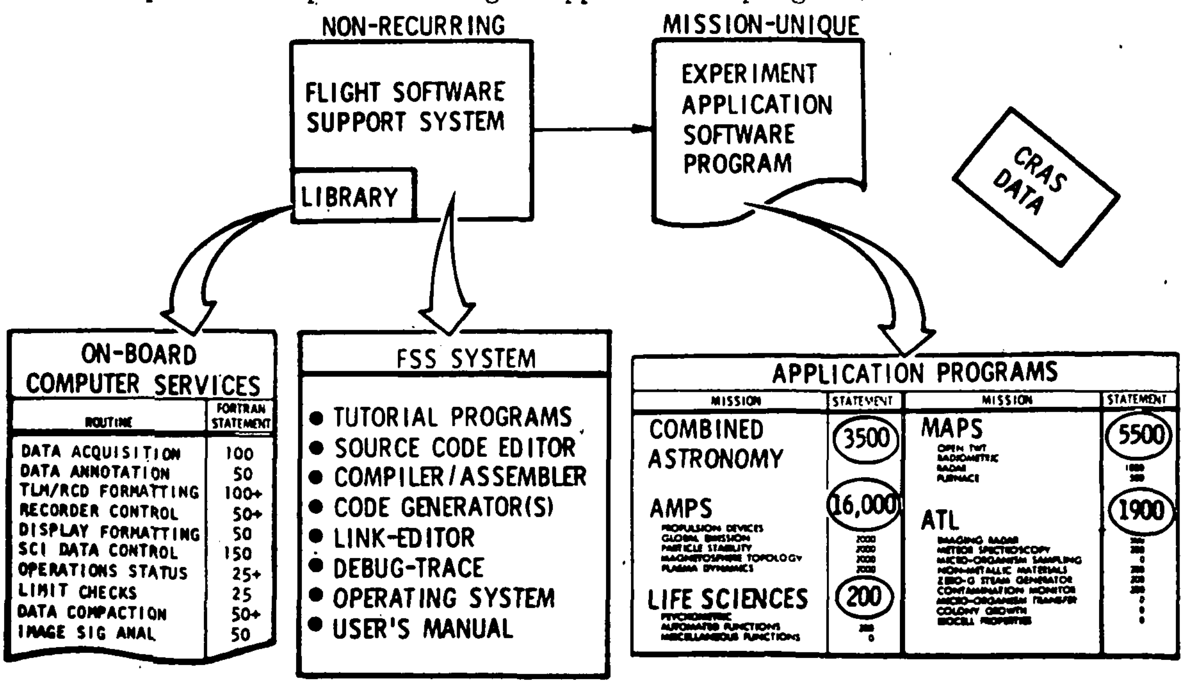


Figure 3.1-2. Software Development Approach

One of the primary characteristics of the FSSS was the inclusion of tutorial software. With this software, an individual unfamiliar with the specific program logic could develop an application program. Thus, each PI with minimal aid from a programmer could develop his own flight software. The FSSS is described in detail in the Appendix.

Estimates for the mission-unique software (flight applications programs) for each of the CRAS representative payloads were devéloped. Note that this software pertains only to the integration of subroutines; the subroutines are developed once and only data tables change from mission to mission.

Introduction of dedicated processors into experiment systems results in new hardware; the CDMS was planned as the provider of on-board services. Both mini-processor and micro-processor systems were synthesized from existing commercial equipment, as shown in Figure 3.1-3. Micro-processors were proposed for single services. Mini-processors were proposed for use with experiments that required interrelated services. Micro-processors were proposed to provide the required on-board computer services for each experiment where the iteration rate would require an excessive proportion of a time-shared mini-processor. If two or more of the required on-board computer services for an experiment were interrelated (such as data acquisition for telemetry, recording and display), a mini-processor was used. Descriptions of a model micro-computer, a model mini-computer, and the mini-computer test set are given in the Appendix.

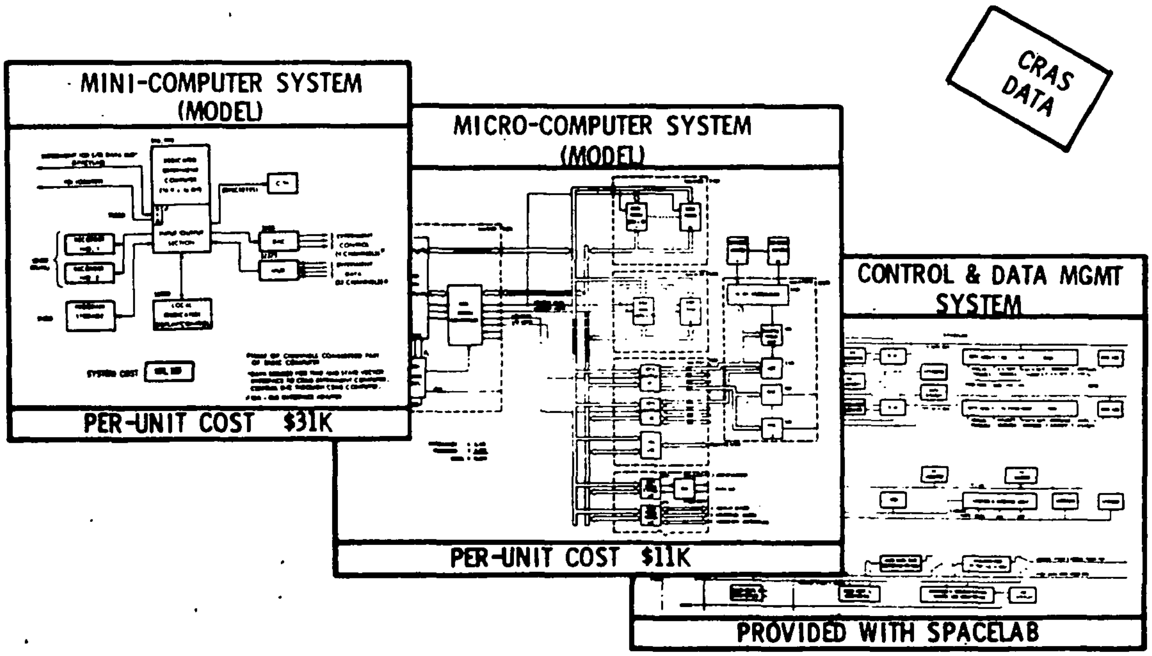


Figure 3.1-3. On-Board Processor Flight Hardware Definition

Micro-processors are not stand-alone assemblies like mini-processors. They do not have power supplies or control panels; they must be incorporated within other experiment equipment. Micro-processors were identified for use in both the dedicated and centralized mechanization approaches. Mini-processors were used only in the dedicated mechanization approach.

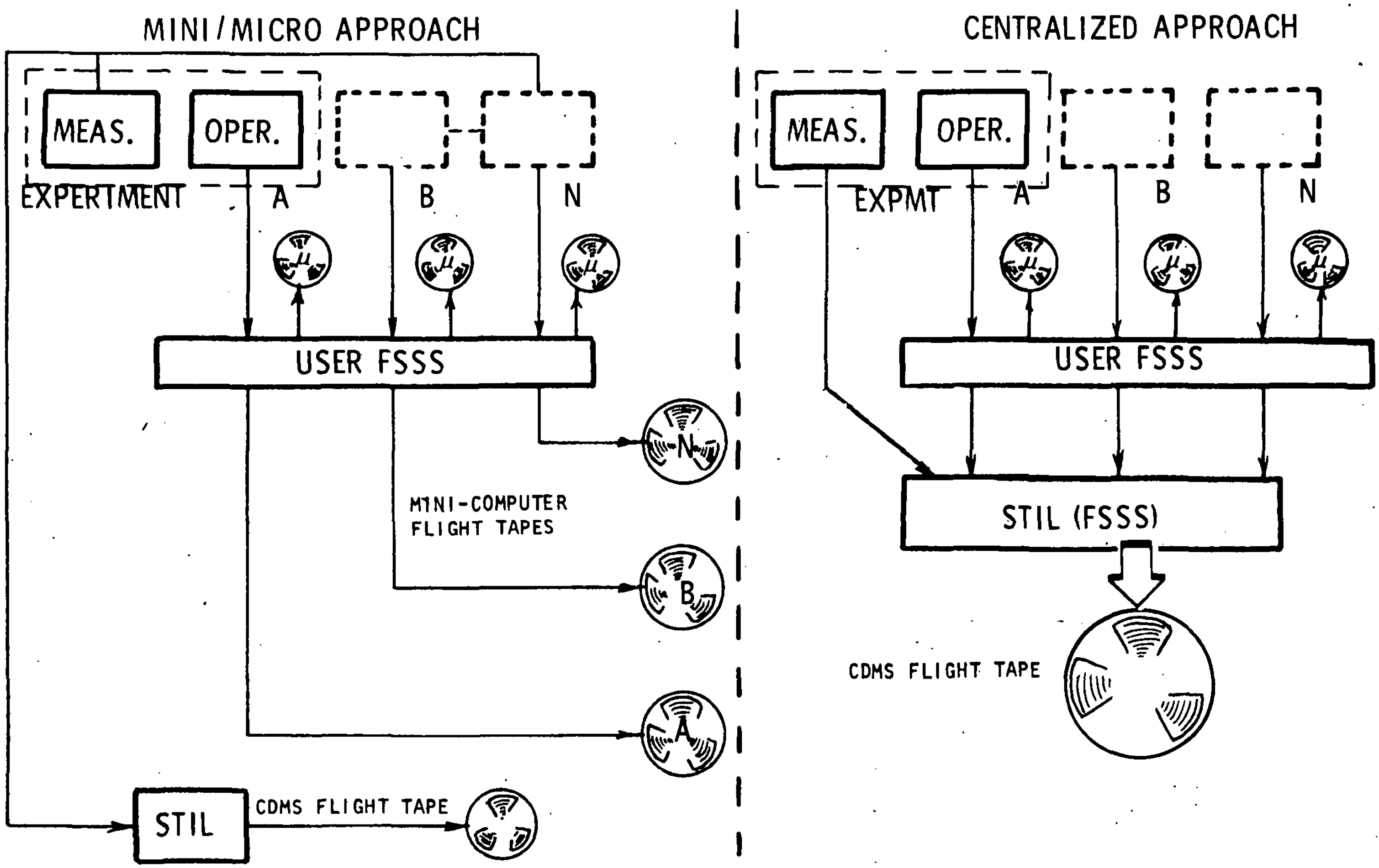
Software development and hardware/software integration techniques were also significantly different for the two approaches. The development flows are illustrated in Figure 3.1-4. With the mini/micro approach, each PI resident programmer, using the FSSS, develops the flight applications software related to experiment operations. Documentation is minimized and validation with his hardware is facilitated. A centralized function [software test and integration laboratory (STIL)] is required for those services that involve the constrained Orbiter interface plus the integrated mission plan.

With the centralized approach, all the software (except for the micro-processor) must be developed at a remoted location and integrated into one flight program for use in the Spacelab CDMS. Not only must the documentation be significantly more formal, but a simulation of the experiment equipment interfaces must be developed to validate the flight software. Considerable host machine time is involved and a CDMS interface simulator is required at payload lead centers to test the centrally developed software with the flight hardware prior to initiation of Level III integration.

Software preparation costs are significantly different. In the mini/micro approach, the computer operations are distributed to individual experiment computers; the PI has his own software prepared by a resident programmer. Coordination is immediate and informal, with only a minimum of documentation. Data from Ames Research Center, where a similar informality applies (ASSESS project), indicates a programming cost, from initial requirements to a proven computer program, of $31/statement.

In the centralized approach the programmer is remote; consequently, considerably more rigor is needed to establish requirements and prove out the program by simulation testing prior to validation by use. There is also the factor that many diverse programs are to be processed by *one* mini-computer (the CDMS), which increases the difficulty of preparing the integrated flight tape. This approach is similar to aerospace practice. Data from Rockwell's computer programming staff indicate that for the centralized approach the programming cost is $62/statement.

In order to develop programmatic cost data, as shown in Figure 3.1-5, an equivalency between the CRAS representative payloads and the remaining payloads of the Spacelab traffic model was defined. Each type of payload was scheduled for three different traffic models. Appropriate cost factors were established for the flight software and hardware, and the ground support equipment for each mechanization approach. A summation of the costs for all the payloads indicated that the costs of the mini/micro or dedicated processor approach was approximately 60 percent of the centralized approach. The estimates included the development of the FSSS, which was recommended for both approaches.



LEGEND:
MEAS. = MEASUREMENT REQMTS (TELEMETRY, CAUTION/WARNING, ANNOTATION)
OPER. = EXPERIMENT OPERATIONS IMPLEMENTED BY COMPUTERS
A,B,N = INDIVIDUAL EXPERIMENTS
STIL = LEVEL III INTEGRATION FACILITY
CDMS = SPACELAB EXPERIMENT COMPUTER
μ = SOFTWARE FOR SINGLE-FUNCTION MICROCOMPUTERS

FLIGHT TAPES - SOFTWARE FOR MINICOMPUTERS OR CDMS
STATEMENTS - FORTRAN OR OTHER HIGH-ORDER LANGUAGE

Figure 3.1-4. Experiment Flight Software Development

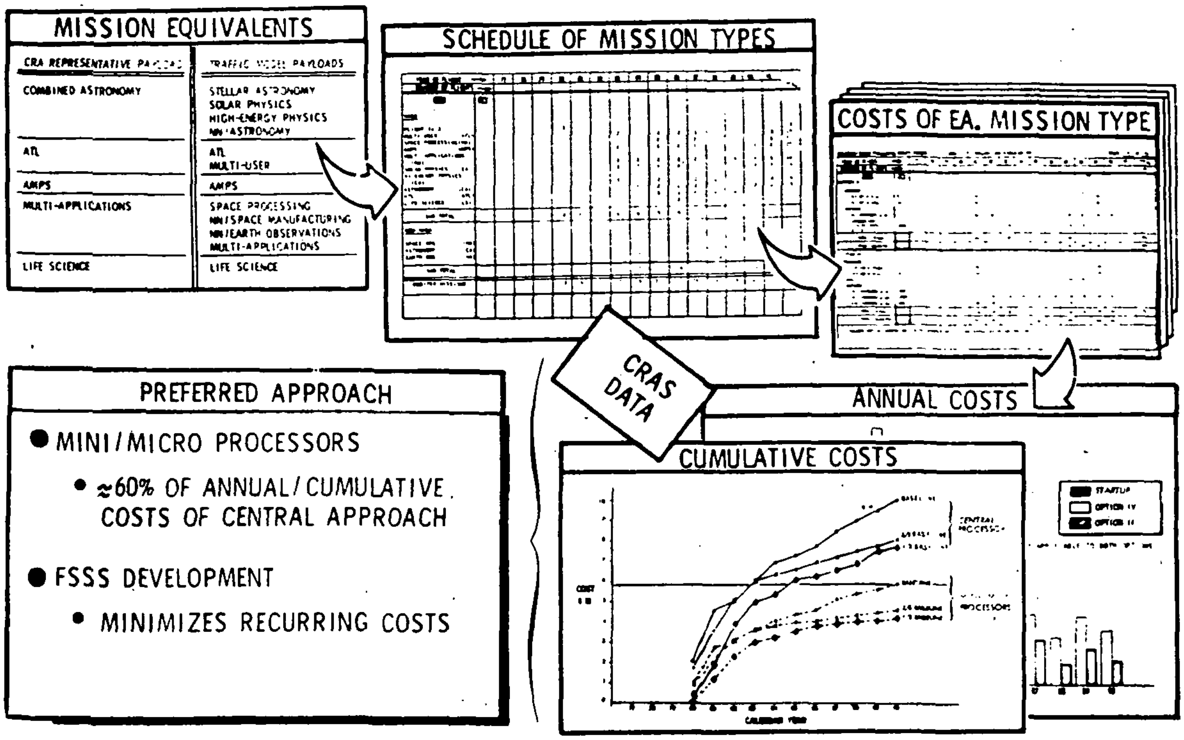


Figure 3.1-5. Programmatic Cost Evaluation

Based upon the cost comparison and the fact that the mini/micro approach facilitates direct participation and control of experiment software by the PI/user, the mini/micro approach was recommended. Thus, in the analyses of this study, the mini/micro approach for mandatory on-board computer services was also adopted.

Each mini/micro processor requires software. A key feature of the mini/micro approach is to enable the user (PI) to prepare his own software without recourse to some central software development facility (such as STIL). Figure 3.1-6 identifies the types and levels of software required.

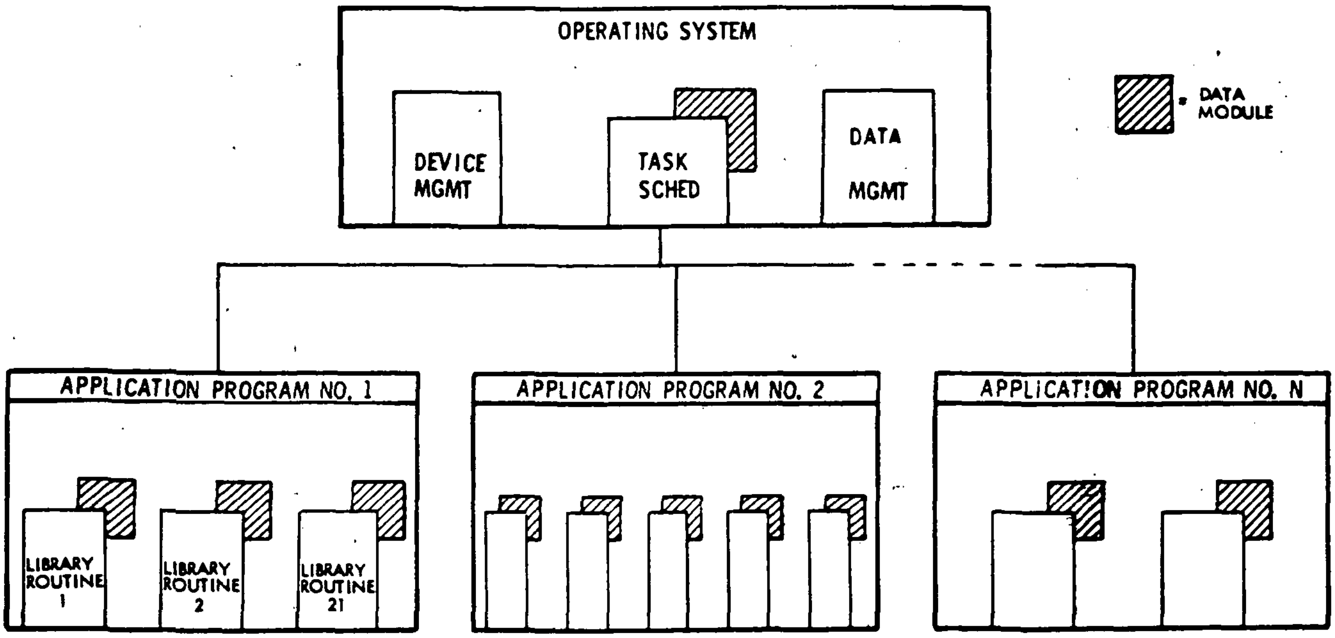


Figure 3.1-6. Software Heirarchy

The basic elements are the library routines, which are equated to the previously identified on-board computer services. The library routine is the working element, is general, and yet can be customized to a particular experiment's requirements by linking to the initialization data. Several routines may be required for a given mode of operation. When linked to the data they then combine into an application program. There may be several application programs for each experiment, applicable to different phases of the mission timeline.

The operating system is that software within the computer that makes the computer work; it is configuration-dependent, and specific for a particular machine. The executive program is the highest-order task within the system, and controls the device (CPU, input/output, peripherals, and memory), and the management of data collected, stored, retrieved, etc., both internally and externally. These elements of the operating system are seldom modified for different applications. The one part of the operating system that is application-unique is the task scheduler. The task scheduler is considered to be another data table--not additional programming.

The flight software support system (see Figure 3.1-7) is the tool by which the user can prepare his own software. It is, itself, software capable of running in the same mini-computer used for flight, if a hard-copy printer (for documenting the program) is added. The FSSS, when installed in the mini-processor with a display terminal, will allow the user to *call* the desired routine; then in a tutorial mode, will guide him in what data tables to create (initialize the routine), and then compile and assemble the machine language code to run in the mini-processor. The FSSS is considered to be a one-time non-recurring cost, and to be used by all users that employ mini- or micro-processors for on-board computer services.

Figure 3.1-8 illustrates the approach recommended in CRAS for the preparation and validation of all on-board software. The user develops his hardware and software at his home site, using the flight computer, configured as a test set for program generation, with the tutorial flight software support system. When the software is prepared, it is immediately run with the experiment hardware to test and validate both the hardware and software concurrently. (This is the same approach that was developed in the original SUIAS). Necessary modifications and rework of both hardware and software continue until the user is satisfied.

Concurrently, the user has identified his telemetry measurement list, caution and warning list, and annotation data requirements, which are transmitted to the Level III mission manager. These requirements, for all experiments of that payload, are integrated into the requirements for the CDMS in its function as a single interface with the Orbiter. The Level III manager has these integrated requirements established as the initialization data for the standard CDMS programs; there is no new programming for the CDMS. Other integration aspects include the preparation of cabling, assignment of RAU connections, etc.

At the proper time, the user ships his completed experiment, mounted in racks and on pallet segments, to the Level III integration site (KSC). Here, the racks/pallets are assembled into modules and the intermodule cabling, etc.,

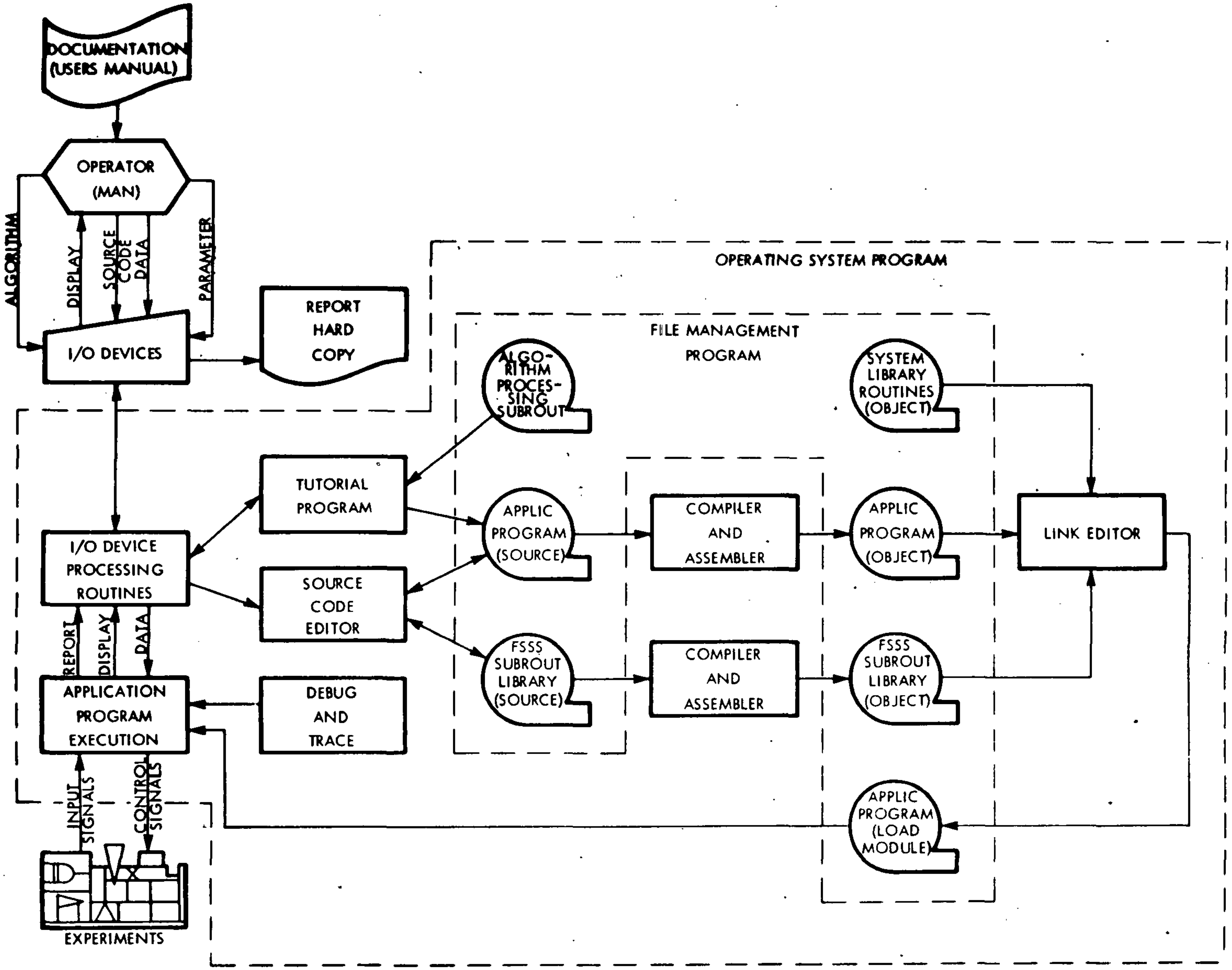


Figure 3.1-7. Flight Software Support System

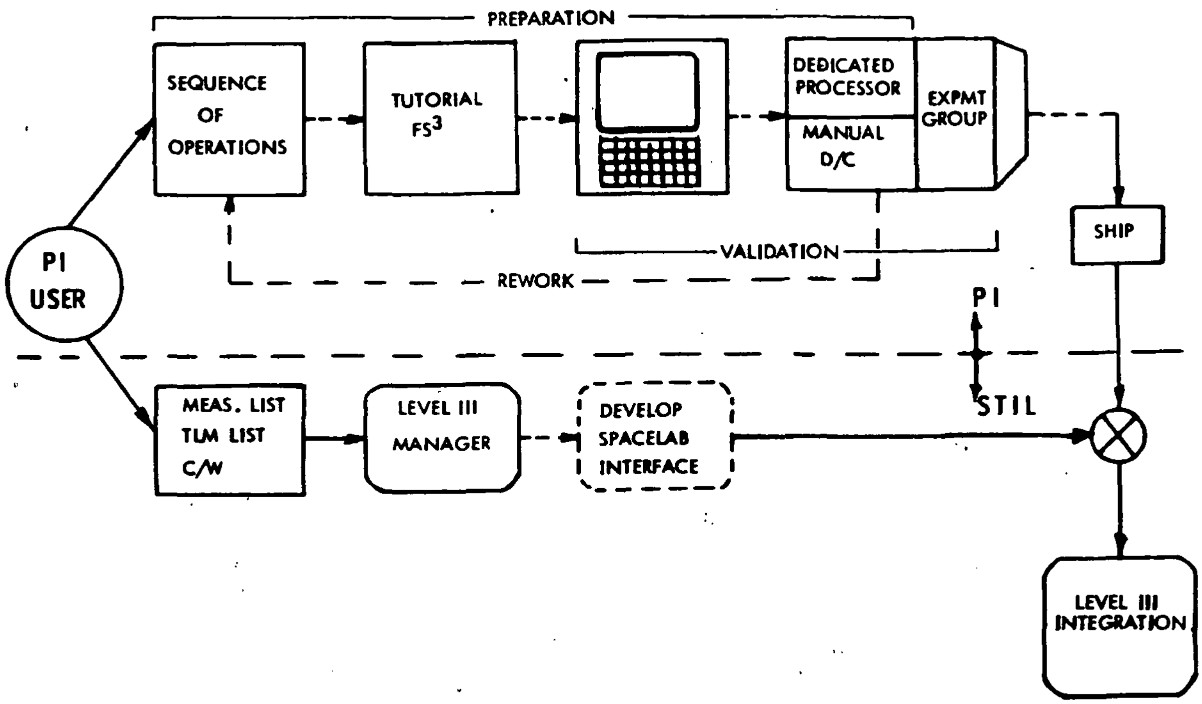


Figure 3.1-8. Mini/Micro Processor Software Preparation/Validation

installed and checked out. The PI or, more specifically, the payload specialist who will operate his experiment, will be present to assist in the integrated CDMS/experiment processing checkout.

3.2 APPLICATION TO ATL PAYLOADS

Applying the methodology developed in CRAS, each experiment of the three reference ATL payloads was analyzed, and the required on-board computer services were assigned to mini/micro or CDMS processors. The guidelines for assignment were as follows.

- Assign only the mandatory centralized services to the CDMS.
- Assign a micro-processor to a single function within the experiment.
- If more than two micros are needed, consider using a mini.
- Retain the micros where the service would overload a mini.
- No more than one mini per experiment; mini's are not shared between experiments.

The number of statements to prepare the flight applications programs was estimated per the following rules.

- 50 statements per micro-processor.
- Number of statements per mini-processor depends upon the number of services required for that experiment: 1 to 4 services, 200 statements; 5 to 8 services, 1000 statements; and over 8 services, 2000 statements.

Figures 3.2-1, 3.2-2, and 3.2-3 show the assignment of mini/micro or CDMS processors for the required on-board computer services for each reference ATL payload.

The results of the assignment of on-board computer services for the three reference ATL payloads are shown in Figure 3.2-4. The requirements, as can be seen, vary with the specific assembly of experiments into one payload.

To aid in the later compilation of programmatic costs, a nominal ATL payload was defined to have a complement of 6 mini-processors, 14 micro-processors, and 2500 statements prepared by the PI's resident programmer for the flight applications software.

In addition to the experiment-dedicated equipment/software costs, there is the additional assessment of the costs for the centralized services performed by the CDMS.

As indicated in Figure 3.2-5, the users transmit their telemetry, annotation, caution/warning, and timeline requirements to STIL, where the composite requirements are integrated into total lists. The bookkeeping activity to produce these lists requires about three man-months per flight. From these integrated requirements the equivalent data tables would be coded (about 300K bytes/flight) and converted into the CDMS machine language, which would require about three hours of S/360 machine time per flight.

Note that there are no new software programs to be developed for the CDMS. Based upon preliminary software specifications, ESA/ERNO will provide software programs for the same type of services for the Spacelab subsystems. Therefore, only new data tables would be required to perform the same services for the Spacelab experiments.

The STIL integration cost/flight was estimated to be $16.6K, and will be constant for each flight. This cost estimate is consistent with the CRAS data, and applies to every flight.

ATL PAYLOD ATL PAYLOAD NO. 1

EXPERIMENT	ON-BOARD COMPUTER SERVICES																											PROCESSOR COMPLEMENT		STATEMENTS
	1 RECORDER CONTROL	2 PRE-PROCESSING	3 OPERATIONS STATUS	4 IMAGE PROCESSING	5 COMMAND GENERATION	6 PLATFORM CONTROL	7 C/W BACKUP	8 QUICK-LOOK ANALYSIS	9 TREND ANALYSIS	10 SCIENCE DATA CONTROL	11 DIGITAL DATA ACQUIS	12 DIGITAL DATA ANNOTA	13 TELEMETRY FORMATTING	14 RECORDING FORMATTING	15 DISPLAY FORMATTING	16 LIMIT CHECKS	17 GRAPHICS PROCESSING	18 AUTOCORRELATION	19 DISPLAY GENERATION	20 SENSOR POINTING	21 SCHEDULED SEQUENCE	22 DATA COMPRESSION	23 COORD TRANSFORMS	24 FOURIER ANALYSIS	25 ZERO-ORDER PREDICTION	26 MATRIX ANALYSIS	27 DATA COMPACTION	MINI-PROCESSORS	MICRO-PROCESSORS	
NV-3 MULTIPATH MEASUREMENTS	M		M		M		C	M		μ	C	C	C	M	M				M	μ		μ						1	3	1150
EO-2 TUNABLE LASERS					M		C				C	C	C	M	M				M									1		200
EO-5 LASER RANGING				μ	M		C				C	C	C	M					M	μ	M						μ	1	3	350
EO-9 RF NOISE	M		M	μ	M		C	M			C	C	C	M	M				M	μ								1	2	1100
PH-2 BARIUM CLOUD RELEASE											C	C	C	μ	μ														2	100
PH-3 AEROSOL PROPERTIES																														
PH-4 NEUTRAL GAS PARAMETERS											C	C	C	M	M		μ		M	μ	M							1	2	300
MB-1 COLONY GROWTH																														
MB-3 BIOELECTRIC FIELD OPACITY											C	C	C	μ							μ								2	100
EN-1 MICRO-ORGANISM SAMPLING																														
CS-X CONTAMINATION MONITOR											C	C	C																	
TOTAL																												5	14	3300

LEGEND

- M = MINI-PROCESSOR
- μ = MICRO-PROCESSOR
- C = CDMS PROCESSOR

Figure 3.2-1. ATL Payload 1 On-Board Processing Requirements

Space Division
Rockwell International

ATL PAYLOAD NO. 2 — EXPERIMENT	1 RECORDER CONTROL	2 PRE-PROCESSING	3 OPERATIONS STATUS	4 IMAGE PROCESSING	5 COMMAND GENERATION	6 PLATFORM CONTROL	7 C/W BACKUP	8 QUICK-LOOK ANALYSIS	9 TREND ANALYSIS	10 SCIENCE DATA CONTROL	11	12 DIGITAL DATA ACQUIS.	13 DIGITAL DATA ANNOTA.	14 TELEMETRY FORMATTING	15 RECORDING FORMATTING	16 DISPLAY FORMATTING	17 LIMIT CHECKS	18 GRAPHICS PROCESSING	19 AUTOCORRELATION	20 DISPLAY GENERATION	21 SENSOR POINTING	22 SCHEDULED SEQUENCE	23 DATA COMPRESSION	24 COORD. TRANSFORMS	25 FOURIER ANALYSIS	26 ZERO-ORDER PREDICTION	27 MATRIX ANALYSIS	28 DATA COMPACTION	COMPLEMENT: MINI-PROCESSORS	COMPLEMENT: MICRO-PROCESSORS	STATEMENTS
EO-3 MULTISPECTRAL SCANNER					M							C	C	C		M					μ	M							1	1	250
EO-6 MICROWAVE ALTIMETRY					M							C	C	C		M				M	μ	M	μ	μ	μ			μ	1	5	450
PH-1 ~~WAKE DYNAMICS~~																															
PH-3 AEROSOL PROPERTIES																															
MB-1 COLONY GROWTH																															
MB-2 MICRO-ORGANISM TRANSFER					μ							C	C																	1	50
MB-4 BIOCELL ELEC CHARACTERISTICS												C	C	C	μ															1	50
MB-5 BIOCELL GENERAL PROPERTIES																															
EN-1 MICRO-ORGANISM SAMPLING																															
EN-3 NON-METALLIC MATERIALS			μ				C					C	C	C						μ										2	100
CS-2 ZERO-G STEAM GENERATOR			μ				C					C	C	C						μ										2	100
CS-X CONTAMINATION MONITOR												C	C	C																	
TOTAL																													2	12	1000

LEGEND

M = MINI-PROCESSOR
μ = MICRO-PROCESSOR
C = CDMS PROCESSOR

Figure 3.2-2. ATL Payload 2 On-Board Processing Requirements

Space Division
Rockwell International

ATL PAYLOAD NO. 3	ON-BOARD COMPUTER SERVICES																												COMPLEMENT		
EXPERIMENT	1 RECORDER CONTROL	2 PRE-PROCESSING	3 OPERATIONS STATUS	4 IMAGE PROCESSING	5 COMMAND GENERATION	6 PLATFORM CONTROL	7 C/W BACKUP	8 QUICK-LOOK ANALYSIS	9 TREND ANALYSIS	10 SCIENCE DATA CONTROL	11	12 DIGITAL DATA ACQUIS.	13 DIGITAL DATA ANNOTA.	14 TELEMETRY FORMATTING	15 RECORDING FORMATTING	16 DISPLAY FORMATTING	17 LIMIT CHECKS	18 GRAPHICS PROCESSING	19 AUTOCORRELATION	20 DISPLAY GENERATION	21 SENSOR POINTING	22 SCHEDULED SEQUENCE	23 DATA COMPRESSION	24 COORD. TRANSFORMS	25 FOURIER ANALYSIS	26 ZERO-ORDER PREDICTION	27 MATRIX ANALYSIS	28 DATA COMPACTION	MINI-PROCESSORS	MICRO-PROCESSORS	STATEMENTS
NV-1 MICROWAVE INTERFEROMETER			M				C			M		C	C	C		M				M			μ					μ	1	2	300
NV-2 AUTONOMOUS NAVIGATION			M				C					C	C	C		M				M				μ					1	1	250
EO-1 LIDAR MEASUREMENTS			M							M		C	C	C		M				M									1		200
EO-4 RADIOMETER	M				M							C	C	C		M				M	μ	M							1	1	1050
EO-7 SEARCH/RESCUE AIDS			M				C			M		C	C	C		M				M								μ	1	1	250
EO-8 IMAGING RADAR			M				C			M		C	C	C		M				M								μ	1	1	250
PH-2 BARIUM CLOUD RELEASE												C	C	C	μ	μ														2	100
PH-4 NEUTRAL GAS PARAMETERS												C	C	C		M		μ		M	μ	M							1	2	300
PH-6 METEOR SPECTROSCOPY			μ									C	C	C		μ				μ										3	150
EN-1 MICRO-ORGANISM SAMPLING																															
EN-3 NON-METALLIC MATERIALS			μ				C					C	C	C						μ										2	100
CS-X CONTAMINATION MONITOR												C	C	C																	
TOTAL																													8	15	2950

LEGEND

M = MINI-PROCESSOR
μ = MICRO-PROCESSOR
C = CDMS PROCESSOR

Figure 3.2-3. ATL Payload 3 On-Board Processing Requirements

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	MINI PROCESSORS	MICRO PROCESSORS	SOFTWARE STATEMENTS
ATL PAYLOAD 1	5	14	3300
ATL PAYLOAD 2	2	12	1000
ATL PAYLOAD 3	7	15	2950
NOMINAL ATL PAYLOAD	6	14	2500
COST FACTORS (CRAS DATA)	$33K EACH	$11K EACH	$31 PER STATEMENT

Figure 3.2-4. ATL On-Board Processing Requirements

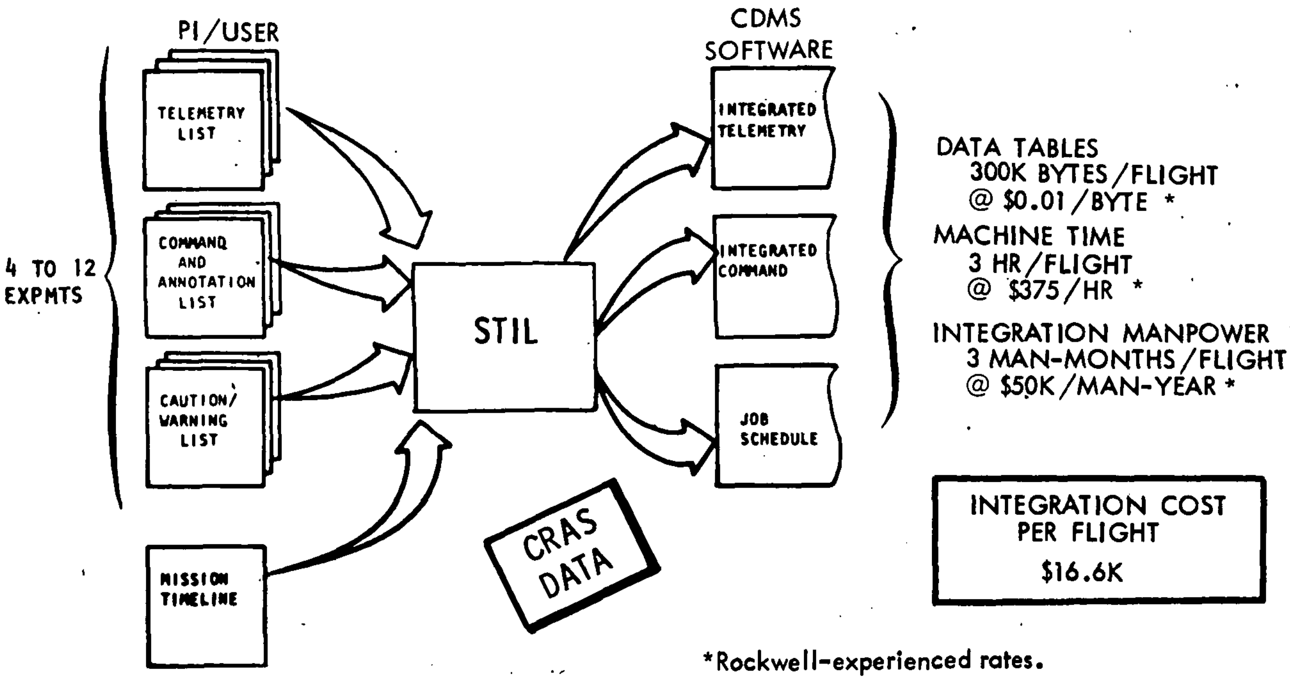

Figure 3.2-5. "STIL" Function with Mini/Micro Processor Approach

4.0 ON-BOARD COMMAND AND CONTROL

The CRAS did not address the man-machine interface (on-board command/control) aspect directly. For the ATL Spacelab, with multidiscipline experiments and many users, and a more comprehensive definition of the experiments, it was both feasible and desirable to investigate alternative methods of implementation, and determine the sensitivity of both cost and user autonomy for these alternatives.

Three basic approaches were selected for evaluation: *manual* (hardwired), *computer-aided*, and *automated*. Figure 4.0-1 illustrates the concepts, and Table 4.0-1 lists the comparative factors.

The hardwired approach is a typical laboratory configuration with hardwired switches, potentiometers, meters, etc. Certain safety-related displays and controls are always hardwired. Even for the maximum hardwired approach, however, there is a need to sample the switch positions, and the engineering data to be displayed for incorporation in the telemetry and recorded data; this service could be provided by the CDMS.

The computer-aided approach substitutes a CRT/keyboard for many of the switches/meters, and adds an experiment command bus (independent of the CDMS experiment data bus); wire count and plug interconnections are reduced, and less payload specialist training is required since a common display/control work station is used. In addition to the CRT/keyboard there will still be some hardwired controls, particularly for rapid response in case of malfunctions.

Automatic control would have the same schematic as the computer-aided approach; the difference is that for automated control the decision-algorithms and sequencing are done with software, with the operator monitoring and (if necessary) overriding the program.

The definition of on-board command and control requirements was derived from the experiment definition data packs and from the in-flight experiment operations flow chart. As shown by Figure 4.0-2, for representative ATL experiments the sequential *checklist* actions performed by the payload specialist operator were defined for each of the appropriate phases of in-flight operations. Initially, these actions were developed as though this were a manual or hardwired laboratory system. Thus, by referring to the dedicated control panel sketch and the checklist it is possible to trace the operator's actions to deploy, set up, verify, etc., the experiment equipment.

For each command/control implementation approach the pertinent cost elements were defined and estimated. Individual panels for each experiment were evaluated for the hardwired approach. Recurring and non-recurring software and hardware cost factors were established for typical ATL experiments for the automated and computer-aided approaches.

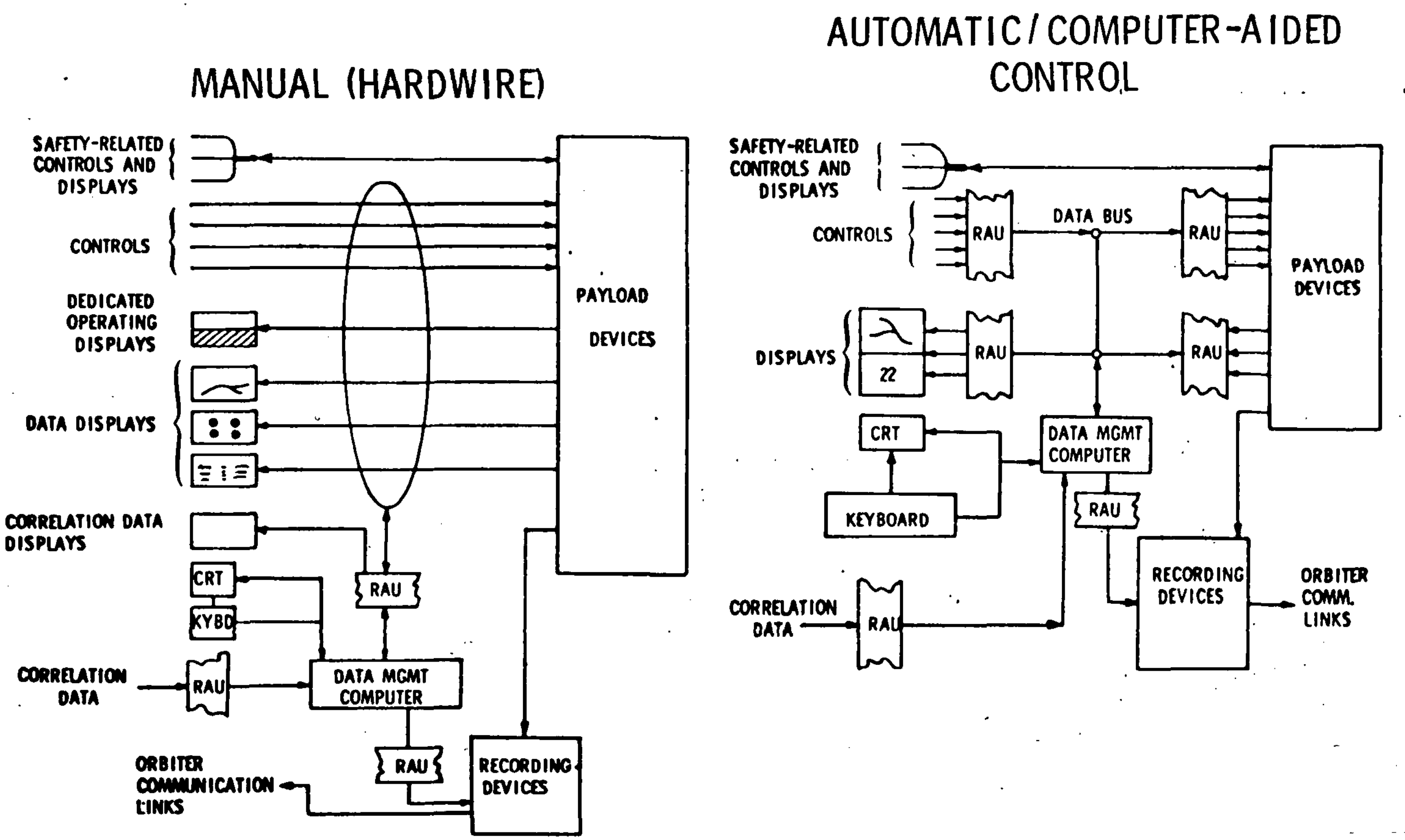

Figure 4.0-1. Data Management Design Concept Comparison

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Table 4.0-1. Design Concept Comparisons

	HARDWIRE	COMPUTER-AIDED CONTROL	AUTOMATIC
CONTROL	• ALL CONTROLS DEDICATED & HARD-WIRED TO EQUIPMENT INPUTS	• MANUALLY CONTROLLED • ALL CONTROLS ROUTED THROUGH RAU's AND EXECUTED BY COMPUTER	• CONTROLS SIMILAR TO OTHER COMPUTER INTERFACE CONCEPTS TO PERMIT MANUAL OVERRIDE • COMPUTER CONTROL OF OPERATIONS, SEQUENCING, & MONITORING
DATA & DISPLAY	• ALL DATA MONITORED IN REAL TIME BY OPERATOR • DISPLAYS REQUIRED FOR CORRELATION DATA	• COMPUTER AVAILABLE FOR DATA TRANSFORMATION, PROCESSING & FORMATTING • KEYBOARD & CRT FOR ADDITIONAL CONTROL & DISPLAY FUNCTION • CORRELATION DATA PROCESSED BY COMPUTER DISPLAYED ON CRT	SAME AS FOR COMPUTER-CONTROLLED
SOFTWARE	• LIMITED TO ESSENTIAL CONVERSIONS & FORMATTING FOR COMM AND RECORDING	• INCLUDES SWITCH SCAN, FUNCTION TRANSFORMING & ROUTING FOR ALL REQUIRED CONTROL, DISPLAY & RECORDING FUNCTIONS	• ALL SOFTWARE REQUIRED FOR COMPUTER-AIDED CONCEPT • ALGORITHMS FOR DECISION-MAKING FUNCTION (POINTING INSTRUCTIONS, START/STOP, CONDITIONALS, ETC.) • SEQUENCING

SAFETY

- ALL CONCEPTS REQUIRE VEHICLE SAFETY-RELATED FUNCTIONS MONITORED & CONTROLLED OVER HARDWIRE PATHS
- COMPUTERIZED CONCEPTS PROVIDE ADDITIONAL MONITORING AND ALERT CAPABILITY OF EXPERIMENT PERFORMANCE

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OPERATOR PROCEDURE

DATE: ____

EXPERIMENT: MICROWAVE INTERFEROMETER (NV-1)
PHASE: X.5 VERIFY OPERABILITY

OPERATOR: ____________

STEP	PROCEDURE	✓	TIME	FAULT
1	RECEIVE ATP TO X.5			
2	SELECT TV CHANNEL 1			
3	SET BOOM TV CAMERA ON			
4	SET TEST LIGHT ON			
5	FOCUS TV CAMERA			
6	CHECK TEST LIGHT VISIBLE & FOCUSED			
7	SET TEST LIGHT OFF			
8	SET BOOM TV CAMERA OFF			
9	SET ELECTRONICS ON			
10	CHECK NO FAULTS VIA BIT			
11	SET TEST TRANSMITTER ON			
12	SET RECEIVER CHANNEL TO POSITION "i"			
13	CHECK S-METER DEFLECTS ALL CHANNELS			
14	SET TEST TRANSMITTER OFF			
15	REQUEST ATP TO X.6			
	REMARKS:			

Figure 4.0-2. Manual Control Procedure Checklist

4.1 HARDWIRED COMMAND/CONTROL COST FACTORS

Hardwired (manual) command and control is done using a control/display panel where the switches and meters are direct-wired to the experiment equipment. Cost factors identified include panel design, the cost of the components, and the activities during development and test of the panel with the experiment equipment.

These cost components were first investigated with an existing experiment system designed for aircraft flight environment that had been developed by Rockwell for Langley. The costs thus experienced were used to verify the conventional cost-estimating relationships used by Rockwell for new developments, and found to correlate well if typical aerospace components are replaced by Mil-Standard components.

Airborne-Practice Cost Model

In order to arrive at realistic cost factors for the ATL control panels, developed in a *model shop* environment, a typical airborne experiment was evaluated. Rockwell developed an S-band radiometer electronics rack for Langley for the AAFE program in a model-shop environment. (See Figure 4.1-1 for a representative panel configuration.) The rack had the following four subassemblies.

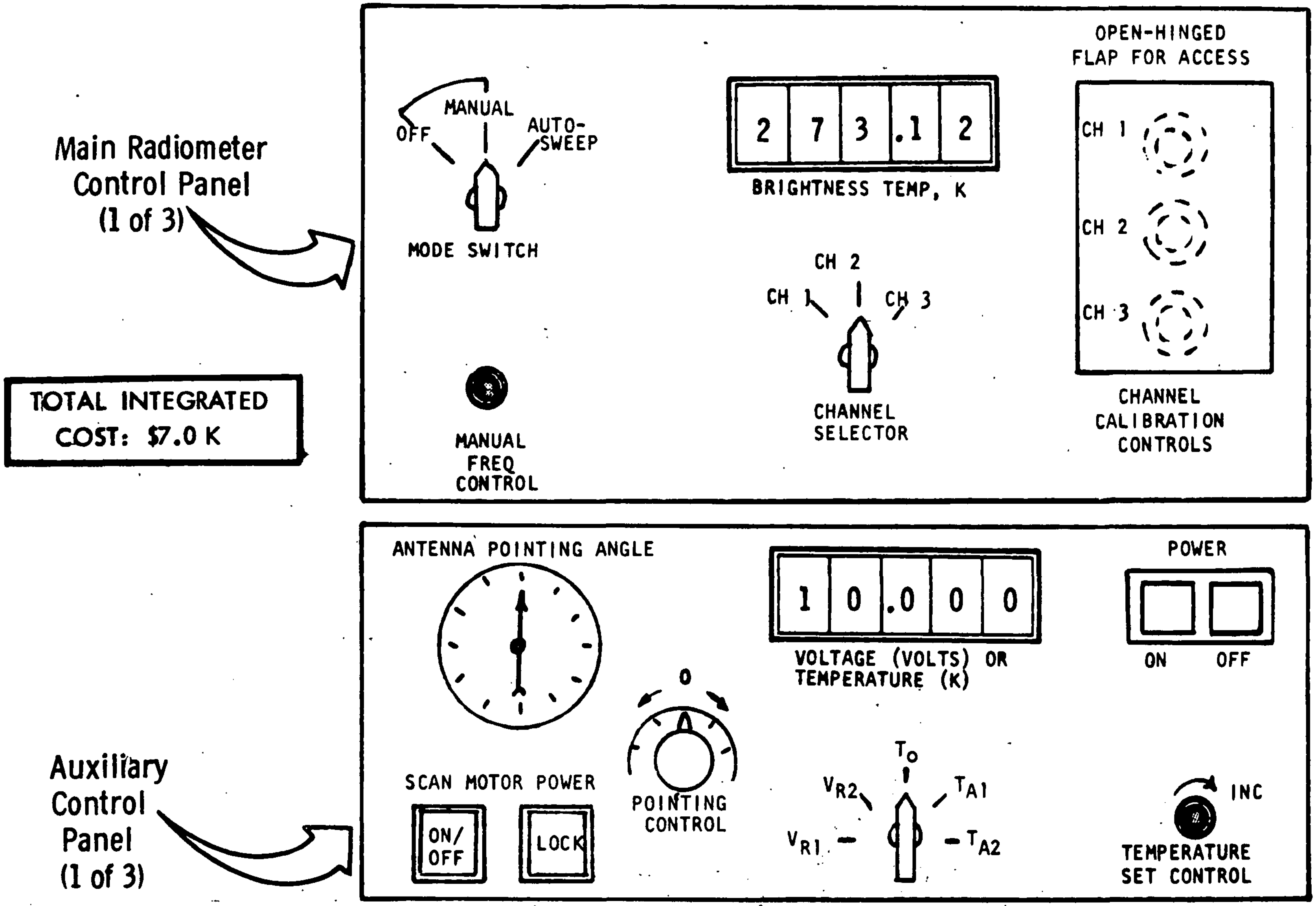


Figure 4.1-1. Existing Manual Control Panel (Microwave Radiometer)

1. Electronics and main control panel ($52.5 K)
   a. Three toggle switches
   b. Two rotary switches
   c. Six potentiometers
   d. Five-digit display

2. Power supply and control panel ($17.5 K)
   a. One rotary switch
   b. Five coaxial jacks
   c. Five-digit display
   d. Servo-driven dial pointer

3. Chart recorder (purchased)

4. Temperature controller (purchased)

The purchased items had self-contained control panels which are not counted. The major part of the cost (Items 1 and 2) was devoted to construction of the electronics. The Rockwell project manager estimates the control panel cost to be 10 percent ($7K) of the total for these two subassemblies. This includes components, layout, mounting, wiring, labeling, testing, and preparation of the Operations Manual data.

The valuation of $7K was derived by examining the historical time and material records of the Microwave Radiometer project manager (Dr. A. Love). With this actual example as a bench mark, it was felt the conventional cost estimating ratios used by the aerospace industry (which are based upon weight) could be verified for credibility.

ATL Control Panel Analysis

The control and display requirements for each ATL experiment were defined in the Experiment Definition task and submitted to Langley in September, 1975. The functional layouts were used to identify the switches, indicators, etc., that would be needed to manually operate, control, and monitor the performance of the experiment, but did not represent the actual control panel designs.

Three factors of significance were evaluated: (1) panel area, (2) panel weight, and (3) panel cost. Area was determined by multiplying the quantities of each type of component by its mounting and spacing requirements. Weight was estimated by using historical aerospace experience. Cost was related to weight by historical cost-estimating ratios developed in the Apollo, Skylab, and ASTP programs.

It was determined that 20 of the experiments had control and display panel requirements. Four of the Biological experiments (MB-1, MB-2, MB-3, and MB-4) had no panel requirements. The approach used was necessarily heuristic because no one panel has been designed in detail. All experiments were broken down into the number of toggle switches, number of event indicators, number of rotary switches, number of digit indicators (2 through 6 digits per meas.), number of panel lights, and the number of TV monitors and oscilloscopes. The TV monitors and oscilloscopes were assumed to be mounted separately in racks. The remaining components were used to size the panels.

Estimated Panel Areas

All panels were assumed to be 19 inches wide. The height was determined empirically based upon the number of toggle switches, event indicators, rotary switches, digit indicators, lights and meters. Each toggle switch or event indicator was counted as one square inch. Rotary switches, digit indicators, lights, and meters were given a number representing their area in terms of the equivalent number of one-inch-square items. Twelve such items were assumed to occupy the 19-inch row, which allows about one-half-inch space between them on the average. The height of the panel was estimated from

$$H = \left(\frac{N}{12}\right) \times 2 + 1 \text{ in.} \qquad (1)$$

Thus, a panel which contained 42 toggle switches, or the equivalent (excluding self-contained units), would be 8 inches high. Equation (1) allows an inch separation between the switch rows for nomenclature. The panel area would be 19 in. x 8 in. = 152 in^2, or 1.1 ft^2.

Estimated Panel Weights

Panel weights were estimated based upon both structural and component considerations. Structural weights were developed from the following relationship, derived from Rockwell experience:

$$W_{panel} = \text{Area of panel} \times 9.2 \text{ lb/in}^2 \qquad (2)$$

Component weights were based upon similar Shuttle-rated equipments. Table 4.1-1 summarizes the weight allowances used.

Table 4.1-1. Shuttle-Rated Component Weight

ITEM	WEIGHT OZ.	WEIGHT LB	COMMENTS
TOGGLE SWITCHES[1]	2.25		
EVENT INDICATORS (FLAGS)			
2-POSITION	1.6		
3-POSITION	5.9		
ROTARY SWITCHES	7.7		
DIGIT INDICATORS[2]			
2-DIGIT		3.0	
4-DIGIT		4.0	A CURVE COULD BE DRAWN
8-DIGIT		6.0	
LIGHTS			
BLOCK OF 8		3.5	THE TRANSFORMER & WIRING WILL HANDLE SEVERAL DOZEN LIGHTS
TRANSFORMER & HARNESS (FOR AC)		3.5	
TV MONITOR		22.0	
MOUNTING BRACKETS		5.5	
CRO		24.9	
MOUNTING		4.9	
POTENTIOMETERS	<2.0		
SINGLE-SCALE D'ARSONVAL		1.2	
SPECTRUM ANALYZER[3]		40.0	TOTAL WT: 61 LB/11 OZ.
IF UNIT	11.9	9.0	
RF UNIT		12.0	

[1]ADD ONE OZ. FOR SAFETY SWITCHES (FLIPPERS)
[2]ESTIMATED
[3]COMMERCIAL UNIT

Table 4.1-2 presents a breakdown of the individual components required by each ATL experiment. Table 4.1-3 summarizes the control panel characteristics and estimated weight.

Note that only discrete control/display functions are reflected in these panel estimates. Integrated, stand-alone display devices such as oscilloscopes, TV monitors, and spectrum analyzers are additional. If these devices are also considered the composite experiment/payload weights would be as indicated in Table 4.1-4. The NASA has been and currently is conducting several parallel studies in an attempt to establish commercial equipments of this type for use by PI's in Spacelab payloads. As these types of equipment are required regardless of the mechanization of discrete controls/displays, integrated displays were not considered in this evaluation except to recognize the required panel space for them. However, because of the limited panel space in the Orbiter aft-flight-deck, these equipments are of concern with the pallet-only Spacelab configuration.

The cost estimation ratio (CER) for control panels built to aerospace standards--based upon Apollo, Saturn, and ASTP programs at Rockwell--is about $1800 per pound. A similar CER for equipment built to military standards--based upon previous DoD programs at Rockwell--is about $170 per pound. Using these CER's and the weight estimates of Table 4.1-3, the panel cost estimates for each ATL experiment/payload are presented in Table 4.1-5.

Imposing manned-space/aerospace standards on Spacelab payload control panels is not considered to be realistic. The rigid documentation and reliability requirements are not warranted because the functions are not crew safety related; they must be operationally safe, but do not provide crew survival/safe return capability. Therefore, design and development of experiment control panels in a *model shop* environment was evaluated. This approach would be equivalent to the technique used in the ASSESS program. Each experimenter was independently responsible for the design, fabrication, and test of his required control panel. Components were selected by the experimenter and ranged from commercial to aerospace ratings. The norm was Mil-Standard. The cost estimates to design, manufacture, assemble, test, and purchase components to Mil-Standard procedures for ATL experiments (Table 4.1-5) ranged from $2K for a simple panel, to $12K for a complex panel, with an average cost of about $5K.

Table 4.1-2. ATL Experiment Panel Components

Experiment	Toggle Switches			Talkbacks		Rotary Switches		Digit Indicators		No. of Lights		Miscellaneous
		Positions		Positions		No. of	No. of	No. of	No. of		Dis-	
	ON/OFF	2	3	1	2	Switches	Positions	Indicators	Digits	Bit	crete	
1. NV-1	7*	2		7	2	1	5	1	3	9		
2. NV-2	9* (1**)			11		3	2 (5-pos.)	11 1	2 6	11		
3. NV-3	10* (4**)			6				1 2	3 3			Sig. strength meter; receiver tuner (2 knobs)
4. EO-1	6 (1**)			5		1	3 (5-pos.)	9	2	9		One analog potentiometer
5. EO-2	13 (3**)			10	1	1	3	3 2	2 2	9		Sig. strength meter; two potentiometers (align, adjust receiver
6. EO-3	8 (4**)	3		4	3	5 1 4	7 5 9/2 gang	9	3	7		
7. EO-4	4	5		9		2 1 1 1	7&4 2 3 5	3 2	3 5	1		5 pots
8. EO-5	8 (4**)			7		2 1	5 4	6	3	10 (9)		
9. EO-6	10			12		3 1	5 3	4 2	3 2	9		
10. EO-7/-8	12*		3 (**)	12		3 1	5 3			20	8	1 analog s. meter; 2 cont. var. potentiometers
11. EO-9	13* (8**)			6		2 1	5 3	1	3	9		1 receiver tuning & control
12. PH-1 CANCELED												
13. PH-2	20 (10**)	1		10		4	5	11	3	9	2	
14. PH-3 NOT AVAILABLE												
15. PH-4	10 (4**)	1		4		1 1	4 7	2	2	9	3	
16. PH-6	2	2		3				2	3	9		
17. MB-1												No panel shown
18. MB-2												No panel shown
19. MB-3												No panel shown
20. MB-4												No panel shown
21. MB-5	10 (4**)					1 3	6 8				13	3 potentiometers 3 thermometers (analog)
22. EN-1	3			3		1 1	3 5	1 1	2 3			
23. EN-3	6*	1		5		1	5				3	
24. CS-2	9	1				3	5	3 1	3 4	8	1	1 potentiometer
25. CS-X	5			3		1 1 1	3 5 6			9		

*TWO OF THE SWITCHES ARE SAFED. (**) MOMENTARY.

Table 4.1-3. Estimated Panel Weight Summary

EXPERIMENT	PANEL LENGTH (IN.)	PANEL HEIGHT (IN.)	PANEL AREA (IN^2)	WEIGHT (LB)	DIGITAL INDIC. (LB)	LIGHTS	TOTAL (LB)
1. NV-1	19	5	95	6.1	3.5	7.0	16.6
2. NV-2	19	9	171	10.9	9.5	11.0	31.4
3. NV-3	19	7	133	8.4	14.0	7.0	30.7*
4. EO-1	19	7	133	8.4	24.5	9.0	42.0
5. EO-2	19	9	171	10.9	14.0	14.5	40.6*
6. EO-3	19	11	209	13.3	31.5	10.0	54.9
7. EO-4	19	11	209	13.3	19.5	8.8	41.7
8. EO-5	19	7	133	8.4	21.0	14.0	43.5
	PLUS PANEL ON LASER AND ELECTRONIC UNIT						
9. EO-6	19	9	171	10.9	20.0	14.0	44.9
10. EO-7/-8	19	11	209	13.3	6.5	21.0	40.9
11. EO-9	19	7	133	8.4	3.5	14.0	26.0
12. PH-1		DELETED					
13. PH-2	19	13	247	15.6	38.5	17.5	71.8
14. PH-3	19	7	133	8.4	6.5	7.0	23.4**
15. PH-4	19	7	133	8.4	6.0	10.5	24.9
16. PH-6	19	5	95	6.1	7.0	10.5	23.6
17. MB-1 18. MB-2 19. MB-3 20. MB-4 21. MB-5	19	9	-	10.9	-	14.0	24.9
22. EN-1	19	5	-	6.1	6.5	3.5	16.1
23. EN-3	19	7	-	6.1	-	7.0	13.1
24. CS-2	19	7	-	8.4	14.5	11.5	34.4
25. CS-X	19	7	-	8.4	3.0	10.5	21.9

*INCLUDES 1.2 LB FOR SIGNAL STRENGTH METER.
**INCLUDES 1.5 LB FOR TEMPERATURE GAUGE.

Table 4.1-4. Experiment Payload Weights

PAYLOAD NUMBER	EXPERIMENT GROUP	WEIGHT (LB)
1	NV-3	129.2
	EO-2	103.9
	EO-5	100.8
	EO-9	144.2
	PH-2	101.5
	PH-3	23.0
	PH-4	552.4
	EN-1	16.1
	CS-X	51.8
	MB-1/3	*
	TOTAL	722.9
2	EO-3	107.6
	EO-6	158.7
	PH-3	23.0
	MB-5	24.9
	EN-1	16.1
	EN-3	13.1
	CS-2	34.4
	CS-X	51.8
	MB-1/2/4	*
	TOTAL	429.6
3	NV-1	44.1
	NV-2	88.7
	EO-1	99.2
	EO-4	41.6
	EO-7/8	127.6
	PH-2	101.5
	PH-4	52.4
	PH-6	23.6
	EN-1	16.1
	EN-3	13.1
	CS-X	51.8
	TOTAL	659.7

Table 4.1-5. Comparison of Aerospace and Mil-STD Costs

PAYLOAD	EXPERIMENT	WEIGHT (LB)	COSTS (1976 $K)	
			AEROSPACE	MIL-STD
1	NV-3	30.7	55.3	5.2
	EO-2	40.6	73.0	6.8
	EO-5	43.5	78.3	7.3
	EO-9	26.0	46.8	4.4
	PH-2	71.8	129.2	12.1
	PH-3	23.4	42.1	3.9
	PH-4	24.9	44.8	4.2
	EN-1	16.1	29.0	2.7
	CS-X	21.9	39.4	3.7
	MB-1/3	*	*	*
	TOTAL		537.9	50.3
2	EO-3	54.9	98.8	9.2
	EO-6	44.9	80.8	7.5
	PH-3	23.4	42.1	3.9
	MB-5	24.9	44.8	4.2
	EN-1	16.1	29.0	2.7
	EN-3	13.1	23.6	2.2
	CS-2	34.4	61.9	5.8
	CS-X	21.9	39.4	3.7
	MB-1/2/4	*	*	*
	TOTAL		420.4	39.2
3	NV-1	16.6	29.9	2.8
	NV-2	31.4	56.5	5.3
	EO-1	42.0	75.6	7.0
	EO-4	41.7	75.1	7.0
	EO-7/8	40.9	73.6	6.9
	PH-2	71.8	129.2	12.1
	PH-4	24.9	44.8	4.2
	PH-6	23.6	42.5	4.0
	EN-1	16.1	29.0	2.7
	EN-3	13.1	23.6	2.2
	CS-X	21.9	39.4	3.7
	TOTAL		619.2	57.9

*CONTROL PANEL NOT REQUIRED.

4.2 COMPUTER-AIDED COMMAND/CONTROL COST FACTORS

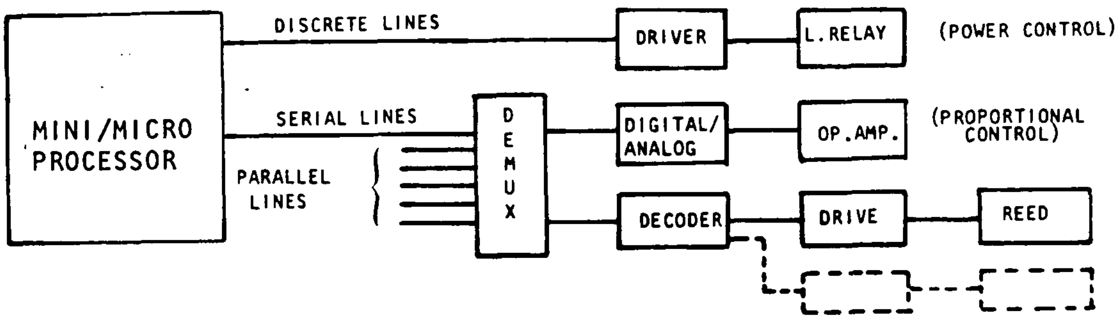
The control and display requirements considered in the computer-aided analysis were the same as those considered in the manual (hardwire) approach. Computer-aided operations monitor and control were considered to be performed using mini-computer display terminal capabilities or the CDMS CRT/keyboard. Control terminology and nomenclature are assumed to be common English; display terms are assumed to be in common engineering units. Procedures for setup, operation, etc., are displayed on the CRT in a tutorial/English language mode.

Quantizable factors include the weight, volume and power requirements of the display terminals (in addition to the CDMS) and the software needed to implement this mode. Since some sharing of display terminals by several experiments is permissible, the evaluation was made on a payload (not experiment) basis.

An important factor which is non-quantizable is the man-machine interface. Because only a few payload specialists must successfully operate 10 to 12 experiments, the training and risk increase markedly for non-standard and non-uniform control/display implementations. The use of a standard display terminal configuration, employing the tutorial procedures, reduces both training and risk.

Replacing hardwired controls with electronic digital signals requires adding terminal hardware at both ends of the transmission system. At the operator end, a display terminal consisting of a CRT readout, an alphanumeric keyboard, and electronic circuitry is required. The quoted cost for this *intelligent* display terminal is $3000; it weighs 44 pounds, requires 260 in^2 of panel area and dissipates 100 watts when in use.

At the experiment equipment end, actuators and decoder elements are required to recognize, interpret and effect the translation of a digital signal to the desired control action. Figure 4.2-1 illustrates how hardwired controls for a typical experiment could be replaced using the experiment mini/micro-processors at the experiment equipment end to interpret a command. The processors are integral components of the experiment design and provide those services defined previously. They have the capability to interface with a display terminal. The processors' capability can be expanded to include the decoding and actuator-driving functions; therefore, their cost is not considered. Only the additional peripheral hardware is listed.



ITEM	COST FACTOR	
INTERFACE HARDWARE	5 LATCH RELAYS	$ 250
	3 DECODERS	30
	3 REED SELECTORS	180
	2 DIGITAL/ANALOG CONVERTERS	80
	2 OPERATIONAL AMPLIFIERS	30
		$ 570
INTELLIGENT TERMINAL	CRT/KEYBOARD WITH INTEGRAL MICROPROCESSOR	$3000
	TOTAL	$3570

Figure 4.2-1. Computer-Aided Hardware Cost Factors (Example: Microwave Radiometer - EO-4)

The cost factors for software preparation were derived in CRAS, and are determined by what functions are desired, and where the software is prepared. Software prepared by the user/programmer, to be implemented in the mini-processor, will cost about $31/statement and $0.01/character for the data tables. Software prepared by STIL (remote program), to be implemented in the CDMS processor, will cost about $62/statement and the same $0.01/character for data tables. If the CDMS CRT keyboard is to be used as a work station, that software is prepared by STIL.

Figure 4.2-2 is a general pictorial of a model mini/micro processing concept, based upon the results of CRAS. A micro-processor (μ) is assigned to those unique/special-purpose functions that might overload the CDMS or mini-processors. Examples are platform stabilization, coordinate transformation, data compression, or image processing. Mini-processors (M) are provided to perform and coordinate more general services such as science data control, recorder format/control, display generation, and command decoding as well as the data acquisition function for each integrated experiment.

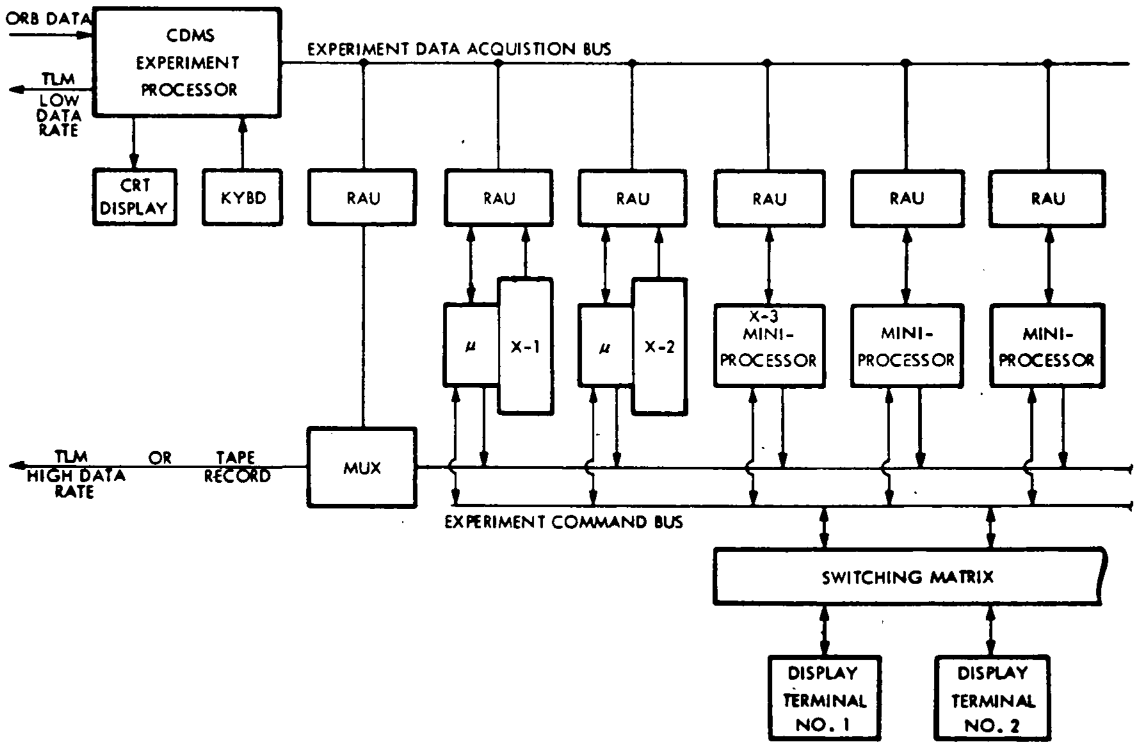


Figure 4.2-2. Level III/II Integration Configuration (Typical)

The CDMS experiment processor provides the housekeeping services interface with the Orbiter avionics--specifically, low-rate telemetry data acquisition and formatting, caution/warning backup and distribution of time, navigation, and attitude data. The interface to the experiment system is between the data bus remote acquisition unit (RAU) and the mini- or micro-processors, and directly to minor support subsystem measurements within the racks or pallets. These housekeeping data are not pertinent to the experiment operation *per se*, but are needed for Spacelab subsystem monitoring and management. Coldplate temperatures, electrical power, voltage regulation, and circuit-breaker status are examples.

The mini/micro processors are the interface to the experiment command bus and the display terminals. The display terminal is a CRT display and an alphanumeric keyboard interconnected with an internal micro-processor and memory--what is called an *intelligent terminal*. The display terminals can be connected to any experiment that includes either a mini- or micro-processor through a manually selected switching matrix.

Three variations for command and control with the mini/micro processing approach were defined as follows.

Variation A --uses the display terminal as a command generation mechanism, replacing manual switch operation with a digitally encoded signal. The experiment command is derived from the Experiment Operations Manual (a book carried along), and the resulting action is verified by examining a CRT display of the corresponding measurements. This variation requires software in the mini/micro processors to decode the command signal, energize the actuators, and acquire the measurement data to be transmitted back to the display terminal for display.

An example measurement display page is shown in Figure 4.2-3. Entries in normal engineering notation are from stored-page data and from real-time data acquisition. Table 4.2-1 indicates the page characteristics which are analogous to the page display format used by the Orbiter. Table 4.2-2 indicates the type of form the user/PI provides for programming (initializing) the data conversion, binary to engineering values.

The measurement display page is customized to a particular experiment by adding the experiment-unique data table. The FSSS may be used for this, provided certain action-analysis software routines are added; these are a one-time, non-recurring cost, estimated to be 1000 statements ($62K). It is also estimated that one measurement display page of 800 alphanumeric characters would be adequate (and required) for each experiment. This data table, at a rate of $0.01/character, would cost about $8.

MICROWAVE INTERFEROMETER

D	H	M	S
12	20	13	05

NO.	NAME	VALUE	UPPER	LOWER	UNITS
1	PALLET POWER	115	120	110	VAC
2	CHANNEL A	-135	-100	-160	dBm
3	CHANNEL B	-122	-100	-160	dBm
4	CHANNEL C	-150	-100	-160	dBm
	⋮	⋮	⋮	⋮	⋮
17	TAPE REMAINING	1200	-	-	FEET
18	TRANS. OUTPUT	20	100	10	mW

Figure 4.2-3. Typical Measurement Display

Table 4.2-1. Data Page Characteristics

DISPLAY FORMAT (CORRESPONDS TO ORBITER MEAS. PAGE)	40 CHARACTERS PER LINE; 26 LINES TOTAL LINE 1 SYSTEM IDENTIFIER AND MET 2 SUBSYSTEM AND NOMENCLATURE 3-23 MEASUREMENT, LIMITS, UNITS 24-25 COMPUTER MESSAGE 26 REMARKS

SPACE	USAGE
1-3	MEASUREMENT, 3 DECIMAL DIGITS
4	SPACE
5-19	NOMENCLATURE, 15 CHAR INCLUDING SPACES
20	SPACE
22-25	VALUE, 3 DECIMAL DIGITS PLUS SIGN
26	SPACE
27-30	UPPER LIMIT, 3 DECIMAL DIGITS PLUS SIGN
31	SPACE
32-35	LOWER LIMIT, 3 DECIMAL DIGITS PLUS SIGN
36	SPACE
37-40	UNITS, 4 ALPHANUMERIC CHARACTERS

ALL ENTRIES WILL BE ALPHANUMERIC, ASC-II, 64-CHARACTER/SYMBOLS

SPACES 22-25 ARE COMPUTER-FILLED @ 12.5/SECOND RATE

OTHERS ARE GENERATED ONCE, REFRESHED BY DISPLAY GENERATOR @ 60/SEC

19 CHARACTER SPACES	=	7	16-BIT WORDS (THREE 5-BIT CHAR/WORD)
15 DECIMAL SPACES	=	5	16-BIT WORDS (FOUR 4-BIT DIG/WORD)
		12	16-BIT WORDS
		x 22	LINES
		262	TEXT WORDS/PAGE
HEADING		+ 17	HEADING WORDS
25 CHAR/LINE		279	WORDS/PAGE
2 LINES			

Table 4.2-2. User Request Form - Data Page

ALL ANALOG/DIGITAL MEASUREMENTS ARE ACQUIRED, HANDLED AS A BINARY FRACTION, ALWAYS POSITIVE, AS AN 8-BIT BYTE.

EACH SAMPLE IS CONVERTED TO ENGINEERING UNITS FOR DISPLAY BY THE FOLLOWING CONVERSION: $Y = ax + b$.

x = RAU OUTPUT
Y = DECIMAL EQUIVALENT
a = PROPORTIONAL CONSTANT
b = OFFSET CONSTANT

CONVERSION IS PERFORMED IN EXPONENTIAL NOTATION; BOTH a AND b ARE WRITTEN IN DECIMAL AS: NNNNNN $\pm$ EE.

NN...N = 6-DIGIT ARGUMENT
EE = 2-DIGIT EXPONENT

THE PI FILLS OUT A FORM SIMILAR TO ONE SHOWN BELOW:

IDENTIFIER	NAME	a	b	UL	LL	UNITS	FLAG
3 DECIMAL DIGIT MEASUREMENT NUMBER (ASSIGNED BY INTEGRATOR)	16 ALPHANUMERIC CHARACTERIS, MAXIMUM (INCLUDING SPACES)	PROPORT. CONSTANT 8 DEC CHAR PLUS SIGN	OFFSET CONSTANT 8 DEC CHAR PLUS SIGN	3 DECIMAL DIGITS PLUS SIGN	3 DECIMAL DIGITS PLUS SIGN	4 ALPHANUMERIC CHARACTERS	NO ENTRY UNLESS CRITICAL

Variation B—is more complex than Variation A; it adds a display of operator's procedures on the CRT and automatically displays the resulting status—an automated checkoff list. This variation requires the same routines as Variation A, and needs additional software to be installed in each processor. Due to the total number of pages of procedures required, extra memory capacity may be required in the mini- or micro-processor.

Figure 4.2-4 is an example of a procedure *page* as displayed on the CRT. Table 4.2-3 indicates the page characteristics which are analogous to the page display format used by the Orbiter. Table 4.2-4 indicates the type of form the user/PI provides for programming. The procedure page is also created using the flight software support system, provided an additional element (software) is provided. This software element is estimated to be 200 statement ($12.4K), non-recurring); its function is to analyze the control action requested and set up the communication from one intelligent terminal to one of several mini- or micro-computers.

There is a maximum of 700 alphanumeric characters per operation verification page, and a maximum of 16 such pages/experiment (one page for each phase of the in-flight operations) for a total of 11,200 characters at $0.01 per character ($112).

MICROWAVE INTERFEROMETER — JUNE 30 14:13:06Z
VERIFY OPERABILITY — MC MILLON

	PROCEDURE	✓ *	TIME	FI
1	RECEIVE ATP X.5	✓	23:13:06M	
2	TV CHAN 1 ON	*		
3	BOOM CAMERA ON	*		
4	TEST LIGHT ON	*		A13
5	ADJUST FOCUS	✓		
6	VERIFY LIGHT VISIBLE	✓		
7	TEST LIGHT OFF			
8	BOOM CAMERA OFF			
9	ELECTRONICS ON			
10	BIT OFF			A14
1	TRANSMITTER ON			
2	RECEIVER CHAN SELECT			
3	SIGNAL ON ALL CHANNELS			A15
4	TRANSMITTER OFF			
5	REQUEST ATP X.6			
	(COMPUTER MESSAGE) (REMARKS)			

✓ = OPERATOR ENTRY   * = CDMS ENTRY   Z = GMT   M = MET

Figure 4.2-4. Computer Display (Aided)

Table 4.2-3. Command Page Characteristics

DISPLAY FORMAT (CORRESPONDS TO ORBITER TUTORIAL PAGE)	40 CHARACTERS PER LINE; 26 LINES TOTAL	
	LINES	
	1	EXPERIMENT IDENTIFIER AND MET
	2	OPERATION AND OPERATION NAME
	3	COLUMN NOMENCLATURE
	4-23	TEST DATA
	24-25	COMPUTER MESSAGE
	26	REMARKS

SPACE	USAGE	
1	SEQUENTIAL STEP	MAIN TEXT
2-28	TEXT (INCLUDING SPACES)	MAIN TEXT
29	CHECKBOX	MAIN TEXT
30	SPACE	MAIN TEXT
31-35	GMT/MET	MAIN TEXT
36-40	FAULT ISOLATION PAGE	MAIN TEXT
1-24	EXPERIMENT NAME	TITLE BLOCK
	OPERATION STEP	TITLE BLOCK
25-40	DATE	TITLE BLOCK
	OPERATOR NAME	TITLE BLOCK
	COLUMN NAME	TITLE BLOCK

ALL ENTRIES WILL BE ALPHANUMERIC, ASCII - 64 CHARACTERS/SYMBOLS

SPACES 29 AND 31-39 ARE COMPUTER FILLED
SPACES 1-28 ARE CUSTOMIZED (PROGRAMMED) ENTRIES } MAIN TEXT

ALL OF TITLE BLOCK IS CUSTOMIZED EXCEPT DATE IS COMPUTER-FILLED

28 CHARACTER-SPACES =	10	16-BIT WORDS (THREE 5-BIT CHAR/WORD)
	x 22	LINES (PROGRAMMED)
	220	WORDS PER PAGE
	x 16	PAGES PER EXPERIMENT
	3520	WORDS/EXPMT (MAX)
	x 11	
	38,720	WORDS/MISSION

Table 4.2-4. User Request Form - Command Page

ALL SWITCHES, INTERLOCKS, BIT ARE MONITORED BY THE DMS AS BI-LEVEL EVENTS.

EACH SAMPLE IS CONVERTED INTO AN ENGLISH-LANGUAGE WORD SUCH AS *ON/OFF, YES/NO, UP/DN, IN/OUT* OR A 6-DIGIT NUMBER. THIS CONVERSION IS A TABLE LOOKUP, KEYED TO THE BIT PATTERN.

THE PI FILLS OUT A FORM SIMILAR TO THE FOLLOWING.

EXPERIMENT IDENTIFIER (24 ALPH CHAR)
SEQUENCE IDENTIFIER (24 ALPH CHAR)

STEP	TEXT	TRUE	FALSE	FI
2 DECIMAL DIGITS (LIMIT, 20 LINES)	20 ALPHANUMERIC CHARACTERS	3 ALPHANUMERIC CHARACTERS	3 ALPHANUMERIC CHARACTERS	2 ALPHANUMERIC CHARACTERS

For Variation B there is an additional flight applications software preparation cost (recurring) that is required. In conventional remote terminal systems many terminals communicate with one central processor and the processor has software to identify each terminal. In the Spacelab flight configuration this situation is reversed--one remote terminal to communicate with several processors. The additional software in the experiment-dedicated mini-processor to recognize its *call sign* and respond (integration software, commonly called *handshaking*), is estimated to be 200 statements at a rate of $31/statement ($6.2K) for each experiment.

Variation C--uses the CDMS as the intelligent terminal during flight. Note that the CDMS CRT/keyboards by themselves cannot be interfaced with the mini/micro processors, but must use the CDMS processor, data bus, and RAU's. The required on-board computer services software remains resident in the mini/micro processors, but the software for command/control (display pages and command signal generation) is prepared by the Level II integration facility (KSC). The estimated cost for using the CDMS as a common work station, as in Variation B, would be

12,000 characters @ $0.01	$ 120
200 statements @ $62	$12,400
3 man-months @ $50K/year	$12,500
2 hours S/360 run time ($375/hour)	$ 750

for a total of about $25K per experiment. However, during the Level IV activities the PI needs his own intelligent terminal to *simulate* the CDMS command/control functions. In CRAS, a CDMS interface simulator was synthesized by utilizing mini-processor elements, but the estimated cost was $150K. It would be unrealistic to impose such a cost factor on each PI.

An alternative to the CDMS interface simulator would be for each PI to use the intelligent terminal from the test set configuration that would be used to develop the flight application programs for required on-board computerized services. But neither the software developed for the CDMS nor the software developed for the mini-processor are directly transferable between processors. Thus, essentially two software developments would be required. Variation C is not recommended.

Variation B, which includes procedure listings and automatic confirmation/status of commands, is preferred. It is recognized that Variation B's recurring costs are about $6.3K greater per experiment than Variation A. However, the versatility, flexibility, potential reduction in operator mistakes, and capability for automatic recording of all in-flight operations with Variation B warrants the additional expense.

Based upon the use of dedicated processors for required on-board services, the delta costs for implementation of the preferred computer-aided command/control approach (Variation B) are presented in Table 4.2-5. The processors, display terminals, and printers that each PI would use for development of on-board services software can also be used for the development of command/control software. Only the actuation hardware, data tables, and integration software are new requirements imposed on each PI. The non-recurring deltas to the FSSS are status display and procedures analysis software. Two flight display terminals are also indicated. These two terminals were assigned to Langley, and would be the actual intelligent terminals installed in the Spacelab for command/control of the experiments. These two terminals would support a flight rate of two per year.

Table 4.2-5. Computer-Aided Delta Cost Factors

RECURRING/EXPERIMENT-UNIQUE	$K	NON-RECURRING/STARTUP	$K
ACTUATION HARDWARE	0.6	FSSS	*
DATA TABLES	0.1	FSSS ADDITIONS STAT. DISPL. 1000 STATEMENTS PROC. ANAL. 200 STATEMENTS	74.4
INTEGRATION SOFTWARE (200 STATEMENTS)	6.2		
MINI-PROCESSORS	*		
DISPLAY TERMINALS	*	2 FLT DISPLAY TERMINALS	6.0
PRINTER	*		

*USE SAME EQUIPMENT AND FSSS AS ON-BOARD PROCESSING CONCEPT.

4.3 AUTOMATED COMMAND/CONTROL COST FACTORS

Automated control of an experiment replaces the man's step-wise switch activations with a computer program. The same hardware and software as defined for computer-aided Variation B are required. However, the decision to proceed to the *next* step is made by the computer program. The operator has the measurements and procedures displayed to monitor and, if necessary, can intervene to modify or overrride the computer's decisions.

To create the software for automating a sequence requires developing a logic flow chart such as shown in Figure 4.3-1. Basicially, this is analogous to the manual steps, with feedback to a decision algorithm. The FSSS cannot be used to create this logic; there is no known *tutorial* method. However, once the logic is developed, the FSSS may be used to code the program.

Based upon Rockwell experience in developing automatic spacecraft subsystems and experiments, it is estimated that to automate a typical/complex experiment would require about 5000 FORTRAN-type statements which, at $31/statement, would cost $155K/experiment.

There are some experiments in the ATL reference payloads that are *automatic*. The Contamination Monitor and the Zero-G Steam Generator, for example, are inherently automated by mechanical timers. These experiments are not complex, do not require extensive operator participation (except to turn ON or OFF), and would be automatically sequenced by means other than an external mini- or microprocessor. Therefore, these *automated* experiments are not used in the programmatic cost evaluation.

EXP: NV-1 MICROWAVE INTERFEROMETER

BLOCK: X.5 VERIFY OPERABILITY

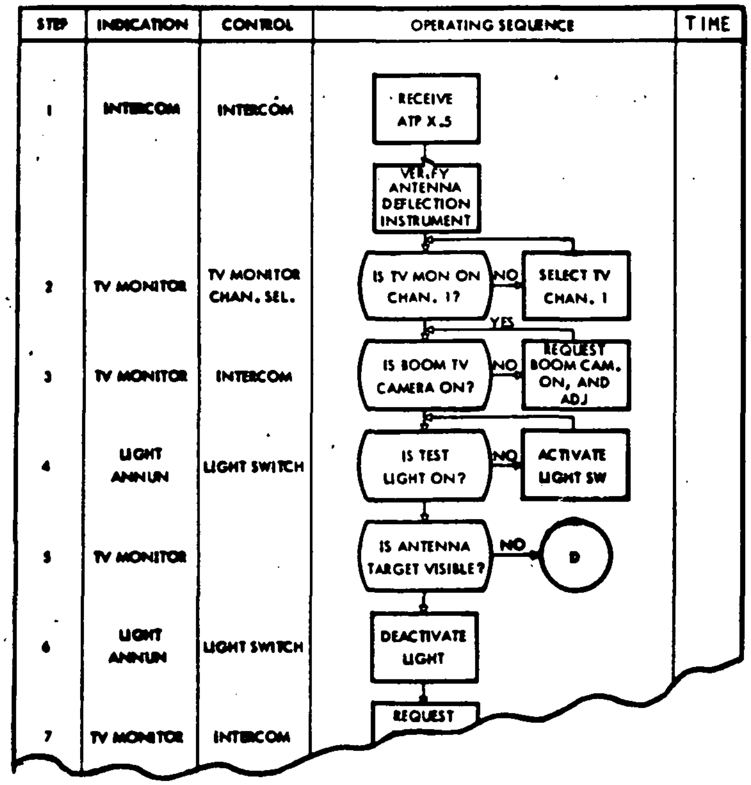


Figure 4.3-1. Automated Control Logic

4.4 COMPARISON OF COMMAND/CONTROL CONCEPTS (PER EXPERIMENT)

Figure 4.4-1 assembles the estimated costs (per experiment) for the three command and control approaches investigated. The large software cost for the automated approach clearly indicates that this is not to be recommended as a general rule, and should be used only when control is critical--either in performance or for safety. An emergency shutdown sequence for a high-powered laser might be an example of where automated control would be required.

Comparison of the average costs of the hardwired and the computer-aided approaches indicates about a $2K difference. However, in terms of pre-flight operator training time, in-flight operation time, and ease of modification the computer-aided approach is preferable where it applies.

Not all experiments could use the computer-aided approach, utilizing a common control station. Some experiments require minimal control, such as turn-on/turn-off action. Others require the operator to transfer samples from a refrigerator to an oven or similar manual transfer operations that are not performed from a common control station. Therefore, both the computer-aided and the hardwired approaches remain viable alternatives.

	HARDWIRED	COMPUTER-AIDED	AUTOMATED
COST FACTORS	PANEL COSTS $5.0K	HARDWARE COSTS $0.6K SOFTWARE COSTS $6.3K	HARDWARE COSTS $0.6K SOFTWARE COSTS $155K
NON COST FACTORS	• INDIVIDUALIZED PANEL FAMILIARIZATION • MANUAL CREW CHECKLIST/ RECORDING • IN-LINE MODIFICATIONS MAY REQUIRE NEW PANEL • CONSTRAINED IN PALLET-ONLY MODE	• COMMON CONTROL STATION • AUTOMATED CHECKLIST/ RECORDING • IN-LINE MODIFICATIONS MAY BE ACCOMMODATED IN DATA TABLES • COMPATIBLE WITH PALLET-ONLY MODE	• SAME • SAME • IN-LINE MODIFICATIONS COULD REQUIRE EXTENSIVE SOFTWARE CHANGES • SAME

VIABLE ALTERNATIVES

NOT RECOMMENDED

Figure 4.4-1. Command/Control Concept Comparison (per Experiment)

5.0 GROUND PROCESSING REQUIREMENTS DATA BASE

For this study, ground operations cover all activities for the analyses, planning, engineering, test operations, and management of the support needed for an ATL flight. Many of these activities require computational assistance either because the calculations are complex, the volume of data is large, or the process is iterative and/or repetitive. Tasks with these characteristics are candidates for automation in some degree.

Other tasks could initially be accomplished manually while the flight rate is low, but because of time criticality they will require automation as the flight rate increases. These tasks are candidates for an interactive semi-automated process. Some other tasks are manual, and it is not feasible to apply automation. An example of this is the Experimenter's Design Manual, which is prepared once and intermittently updated.

The above guidelines are used as criteria to judge which processes should be automated. Another guideline is to restrict automation to those processes where automation is essential (i.e., do not automate a process just to fill up a computer). The most important guideline is to configure the automated process for ease of use by non-specialists in that process; it should not be necessary to hire an orbital mechanics specialist to calculate and plot a ground trace.

Applying this philosophy, a number of essential and optional software modules were identified, sized and evaluated for availability to Langley's use. Several methods of providing this capability to the user were analyzed, and the cost of implementation was determined. From both the economic and user-benefit viewpoints, a dedicated mini-computer with tutorial/interactive software is most advantageous.

5.1 IDENTIFICATION OF GROUND PROCESSING REQUIREMENTS.

The approach used is illustrated in Figure 5.1-1. The basic SUIAS had developed a work breakdown structure (see Figure 5.1-2) that identified the

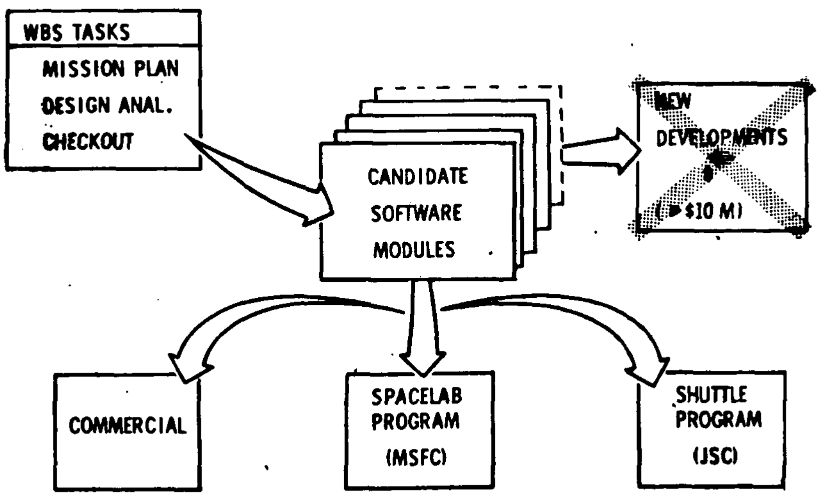


Figure 5.1-1. Ground Operations Requirements

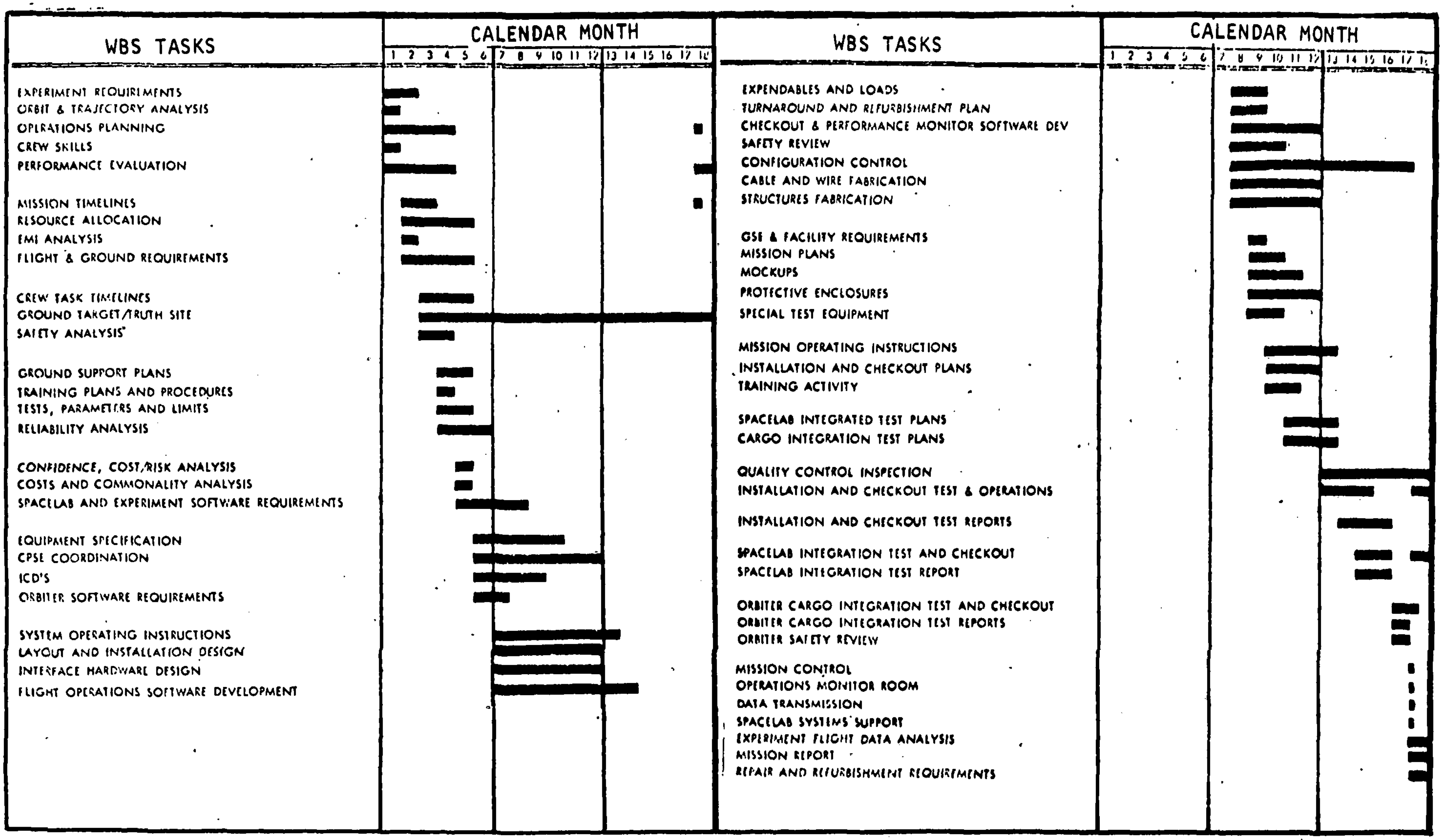


Figure 5.1-2. Mission Integrator's Operations

Space Division
Rockwell International

activity and time phase/duration of the mission integrator's activities. Each task was re-examined and the activity evaluated for both process and timing. As shown in Table 5.1-1, 29 computer-supported processes were identified as being essential for one or more of the criteria mentioned above.

Table 5.1-1. Essential Computer-Supported Activities

- EXPERIMENT GROUPINGS
- SYSTEM/PROGRAM COST ANALYSIS
- GROUND TRACE GENERATOR
- TARGET OPPORTUNITY GENERATOR
- COMMUNICATIONS COVERAGE
- SOLAR/MISSION GEOMETRY
- RADIATION ENVIRONMENT
- ORBIT CONTAMINATION
- ATMOSPHERE MODEL
- ORBIT DECAY
- ORBIT MANEUVERS
- ORBIT ERROR ANALYSIS
- SUBSATELLITE MOTION ANALYSIS
- *MISSION CONSUMABLES*
- ORBITER ATTITUDE MANAGEMENT
- INSTRUMENT POINTING
- MISSION TIMELINE GENERATION
- EXPERIMENT DATA PROCESSING
- ORBIT EPHEMERIS/TIMELINE UPDATE
- CONTINGENCY OPERATIONS PLANNING
- SUBSYSTEMS PERFORMANCE MONITOR
- GROUND TRUTH COORDINATION/CONTROL
- PAYLOAD (EXPERIMENTS) STATUS MONITOR
- THERMAL ANALYSIS
- MASS PROPERTIES ANALYSIS
- LOADS/STRESS ANALYSIS
- ELECTRICAL POWER ANALYSIS
- DATA MANAGEMENT ANALYSIS
- *STABILIZATION CONTROL ANALYSIS*

Each of the 29 processes was described on a data sheet, illustrated in Figure 5.1-3, indicating what it is to do, what inputs are required, what outputs are received, and to which activities it applies. This data sheet is essentially the beginning of a computer program specification. Data sheets for each of the 29 programs are included in the appendix.

CODE

TITLE: SOLAR/MISSION GEOMETRY

FUNCTION/PROCESS:

GENERATE SUN ANGLES (LINE OF SIGHT) WITH RESPECT TO TARGET DIRECTIONS AND COMMUNICATION LINE(S) OF SIGHT. DETERMINE SUN RISE AND SET TIMES (OCCULTATION HISTORIES) AND SURFACE LIGHTING (LOCAL TIME) ALONG THE ORBIT GROUND TRACE. CONSIDER VARIATIONS IN ORBIT CHARACTERISTICS AND INITIAL CONDITIONS.

INPUTS:

CANDIDATE ORBITS AND INITIAL CONDITIONS
SPECIFIED TARGET LOCATIONS
SPECIFIED COMMUNICATION SATELLITE LOCATIONS

OUTPUTS:

SUN-ANGLE HISTORIES
SURFACE LIGHTING CONDITIONS

APPLIES TO WBS:

10-30-	ADVANCE EXPERIMENT/MISSION DEFINITION
30-10-	MISSION REQUIREMENTS
50-10-	SYSTEM REQUIREMENTS AND ANALYSIS

PROGRAM CHARACTERISTICS:

MACHINE, INSTRUCTION SIZE, DATA SIZE, RUN TIME AVAILABLE, CONVERTIBILITY TO INTERACTIVE USE

Figure 5.1-3. Typical Process Data Sheet

The 29 data sheets were analyzed by the Rockwell programmer staff to determine what application and library routines would be needed, and their size in terms of number of FORTRAN statements; see Figure 5.1-4. The total number of statements (218,000) multiplied by a cost estimating ratio of $62/statement indicates the cost of new development of this software would exceed $10 million. The new development approach for Langley was rejected.

In addition to the 29 essential processes, there is a number of documentation areas that could benefit by computer-supported processes where there are large quantities of data. The SUIAS defined 25 essential documents. These were reviewed and evaluated to identify the nature of the process; see Table 5.1-2. Each process was then categorized as manual or automated (a batch process) for the initial ATL flights. When the flight rate increases to 4 or more per year, it will be desirable to modify some of these to an interactive/semi-automatic mode. Only the five documents identified (Table 5.1-2) as initially automated were considered in the implementation analysis.

5.2 AVAILABILITY OF GROUND PROCESSING SOFTWARE

Applicable ground processing programs have been developed by both NASA centers and commercial (Rockwell) contractors. Copies of the 29 essential program descriptions were sent to JSC and MSFC for evaluation. The results are shown in Figure 5.1-5 (JSC) and Figure 5.1-6 (MSFC). Although programs of a similar nature had been developed at JSC, only those shown (Figure 5.1-5) were currently (October 1975) active and applicable. At that time there were no plans to develop programs for payloads, nor to develop tutorial software for existing programs.

The response from MSFC was exceptionally favorable. The correlation between what programs were required and those programs already developed, or being developed at MSFC, was very good. All MSFC programs listed are running in their S/1108, most have been recompiled for an S/360, and some have been run in a mini-computer (a PDP 11/45). Further, these programs include a tutorial initialization program so that an unskilled user can select, initialize, and run these with minimal programmer assistance.

Only two essential programs (stabilization and control analysis, and system/program cost analysis) were not included in the MSFC list. Langley (Flight Dynamics and Control Division) has tutorial software. Rockwell developed a system/program cost analysis model as part of the Radiometer and basic SUIAS effort. Conversion of the operations manual to tutorial software would be a relatively minor task. Specific correlation between the MSFC programs and those programs recommended for documentation tasks was not achieved. However, MSFC's Integrated Mission Program (Figure 5.1-6) should suffice for the mission plan document; the payload activity scheduling program (or Langley's MASS program) can be used for resource scheduling documentation; and commercially available programs can be used for the remainder of the documentation tasks.

Adaptation of the MSFC and commercial programs to run at Langley involves converting, translating, or recompiling the source program (a FORTRAN listing) to fit whatever machine Langley would use. In the optimum case, the cost would be for only the machine time to compile the program. In the worst case, an S/360 to S/unknown translator would be required, which is estimated to cost $700K.

PROCESSES ⇩ / ROUTINES ⇨	TRAJECTORY/ORBIT POSITION (EPHEMERIS)	PLOTTING ROUTINE	SOLAR POSITION	DATA MANAGEMENT	COORDINATE TRANSFORM	MATRIX ANALYSIS	EXPERIMENT DEFINITIONS	EXPMT CONFIGURATIONS & OPERATIONS	EXPERIMENT PRIORITY	EXPERIMENT DEVELOPMENT PLANS/SCHEDULES	TERRESTRIAL/CELESTIAL POSITION	COMMUNICATION SATELLITE POSITION	ORBITER/SPACELAB CHARAC. (MASS & CONFIGURATION)	ERROR SOURCE & MAGNITUDES	SUBSATELLITE PROPERTIES & DEFINITION	MISSION PROFILES	DATA DEFINITION	FORTRAN PROGRAM STATEMENTS (PROCESSES)
EXPERIMENT GROUPINGS				X			X	X	X									500
SYSTEM/PROGRAM COST ANALYSIS				X				X		X						X		1500
GROUND TRACE GENERATOR	X	X		X	X	X												1000
TARGET OPPORTUNITY GENERATOR	X	X		X	X	X					X							1000
COMMUNICATIONS COVERAGE	X	X		X	X	X					X	X						500
SOLAR/MISSION GEOMETRY	X	X	X	X	X	X					X	X						700
RADIATION ENVIRONMENT	X	X		X						X								300
ORBIT CONTAMINATION	X	X		X			X	X		X						X		1000
ATMOSPHERE MODEL(S)	X			X			X											500
ORBIT DECAY	X			X	X	X							X					1200
ORBIT MANEUVERS	X			X	X	X					X		X					1500
ORBIT ERROR ANALYSIS	X	X		X	X	X								X				1000
SUBSATELLITE MOTION ANALYSIS	X	X		X	X	X	X	X							X			1200
MISSION CONSUMABLES				X			X						X			X		1000
ORBIT ATTITUDE MANAGEMENT	X			X	X	X		X			X							2000
INSTRUMENT POINTING	X			X	X	X		X		X	X					X		1500
MISSION TIMELINE GENERATION	X	X		X	X	X	X	X	X	X	X		X		X	X		8000
EXPERIMENT DATA PROCESSING				X	X		X	X		X						X	X	100,000
ORBIT EPHEMERIS/TIMELINE UPDATE	X	X		X	X	X												1000
CONTINGENCY OPS. PLANNING	X	X		X	X	X	X	X	X	X						X		5000
SUBSYSTEMS PERFORM. MONITOR				X			X	X	X	X						X		2500
GRND TRUTH COORD. CONTROL	X			X			X	X	X	X						X		1000
PAYLOAD (EXPMTS) STATUS MONITOR				X			X	X	X	X						X		5000
THERMAL ANALYSIS	X	X		X	X	X	X									X		3000
MASS PROPERTIES & ANALYSIS				X				X					X			X		5000
LOADS/STRESS ANALYSIS				X			X						X					5000
ELECTRICAL PWR ANAL & REQMTS				X			X	X								X		5000
DATA MANAGEMENT ANALYSIS				X												X	X	3000
STABILIZ. & CONTROL ANALYSIS				X			X						X			X		5000
																		TOTAL • 164,900
FORTRAN PROGRAM STATEMENTS (ROUTINES)	1000	500	500	5000	100	500	5000	5000	500	3000	5000	1000	5000	1000	5000	10,000	5000	TOTAL • 53,100

Figure 5.1-4. Ground Processing Size Estimates

Table 5.1-2. Optional Processing Documentation

DOCUMENT TITLE	FLIGHTS/YEAR	2	3	4	5	RATIONALE
1. MASTER PROGRAM PLAN AND SCHEDULE		M	M	I	I	PERT MODEL
2. CONFIGURATION MANAGEMENT REPORT (MONTHLY		M	M	I	I	PERT MODEL
3. LOGISTICS PLAN		M	M	I	I	PERT MODEL
4. INVENTORY REPORT		M	M	I	I	INVENTORY RECORDS
5. EXPERIMENT REQUIREMENTS		M	M	M	M	EXPERIMENT-UNIQUE
6. RESOURCE ALLOCATION PLANS	(X)	A	A	I	I	OPTIMIZATION PROCESS
7. MISSION FLIGHT PLAN	(X)	A	A	A	A	OPTIMIZED RESULT
8. EXPERIMENT OPERATING INSTRUCTIONS		M	M	M	M	USER DEVELOPS
9. GROUND SUPPORT PLAN	(X)	A	A	I	I	PERT MODEL
10. MISSION TURNAROUND AND REFURBISHMENT PLAN		M	M	M	M	UNIQUE PER FLIGHT
11. DATA REDUCTION REPORT		M	M	M	M	MISSION-UNIQUE
12. TRAINING PLAN AND PROCEDURES		M	M	M	M	MISSION-UNIQUE
13. INSTRUMENTATION LIST		M	M	I	I	MISSION-UNIQUE
14. EXPERIMENT RESOURCE REQUIREMENTS	(X)	A	A	I	I	SUPPORT TIMELINE ANALYSIS
15. EMC (TEST REQUIREMENTS) PLAN		M	M	I	I	STANDARD
16. SPACELAB USER'S GUIDE		M	M	M	M	ONE-TIME
17. EXPERIMENTER'S DESIGN MANUAL		M	M	M	M	ONE-TIME
18. TEST REQUIREMENTS		M	M	M	M	MISSION-UNIQUE
19. GSE AND FACILITIES PLAN	(X)	A	A	I	I	PERT MODEL
20. SYSTEM REQUIREMENTS MANUAL		M	M	M	M	SPACELAB-UNIQUE
21. EQUIPMENT SPECIFICATIONS		M	M	I	I	EXPERIMENT-UNIQUE
22. EQUIPMENT OPERATING INSTRUCTIONS		M	M	I	I	EXPERIMENT-UNIQUE
23. INSTALLATION LAYOUT DRAWINGS		M	M	I	I	AUTOMATIC DRAFTING
24. CRITICAL DESIGN REVIEW (CDR)		M	M	M	M	MISSION-UNIQUE
25. MASS PROPERTIES REPORT (SPACELAB & EXPMTS, MONTHLY)		M	M	I	I	ENGINEERING RECORDS
26. INTERFACE CONTROL DOCUMENTS (4)		M	M	M	M	STANDARD
27. SOFTWARE REQUIREMENTS		M	M	M	M	EXPERIMENT-UNIQUE
28. DATA REQUIREMENTS REPORT		M	M	I	I	MISSION-UNIQUE
29. RELIABILITY, MAINTENANCE PROGRAM PLAN		M	M	M	M	ONE-TIME
30. FAILURE MODES EFFECTS ANALYSIS (FMEA)		M	M	M	M	EXPERIMENT-UNIQUE
31. SAFETY STANDARDS & CRITERIA (SYSTEMS SAFETY PLAN--SSP)		M	M	M	M	ONE-TIME
32. INDIVIDUAL TEST PROCEDURES						
A. EXPERIMENT INSTALLATION & CHECKOUT		M	M	M	M	EXPERIMENT-UNIQUE
B. SPACELAB INTEGRATION		M	M	M	M	MISSION-UNIQUE
C. CARGO INTEGRATION		M	M	M	M	STANDARD
33. TEST SUMMARY REPORTS (8)						
A. EXPERIMENT INSTALLATION & CHECKOUT		M	M	M	M	EXPERIMENT-UNIQUE
B. SPACELAB INTEGRATION		M	M	M	M	MISSION-UNIQUE
C. CARGO INTEGRATION		M	M	M	M	MISSION-UNIQUE
34. TEST DATA REPORTS						
A. EXPERIMENT INSTALLATION & CHECKOUT		M	M	M	M	EXPERIMENT-UNIQUE
B. SPACELAB INTEGRATION		M	M	M	M	MISSION-UNIQUE
C. CARGO INTEGRATION		M	M	M	M	MISSION-UNIQUE
35. FAILURE SUMMARY REPORTS						
A. EXPERIMENT INSTALLATION & CHECKOUT		M	M	I	I	ENGINEERING RECORDS
B. SPACELAB INTEGRATION		M	M	M	M	MISSION-UNIQUE
C. CARGO INTEGRATION		M	M	M	M	MISSION-UNIQUE

LEGEND:

M MANUAL
A AUTOMATED (BATCH)
I AUTOMATED, INTERACTING
(X) INITIAL FIVE PROGRAMS

PAYLOAD SUPPORT SOFTWARE (ROCKWELL IDENTIFIED) / AVAILABLE JSC TRAJECTORY-RELATED SERVICES	AOS & LOS PREDICTION - VEHICLE	GROUND TARGET ACQ & LOS	GRND TARGET LOOK-ANGLES FOR GIVEN ORBIT	GEOMAGNETIC LOCATION	VEHICLE ATTITUDE HISTORY	VEHICLE ORBITAL ELEMENT HISTORY	CELESTIAL TARGET POINTING/ACQ & LOS	CONSUMABLES USE PRE-DICTIONS FOR MANEUVERS	ACCELERATION-LEVEL PROFILE HISTORIES	RELATIVE MOTION DETERMINATION	GRAVITY GRADIENT	EARTH LIGHTING	SPACECRAFT LIGHTING	TARGET ON HORIZON	OCCULTATION COMPUTATIONS	ORBIT DECAY PREDICTIONS	ORBIT PRECESSION	AOS & LOS ORBITING TARGET	PLANETARY MOTION
EXPERIMENT GROUPINGS																			
SYSTEM/PROGRAM COST ANALYSIS																			
GROUND TRACE GENERATOR	■	■	■				■							■	■				■
TARGET OPPORTUNITY GENERATOR																			
COMMUNICATIONS COVERAGE												■	■						
SOLAR/MISSION GEOMETRY																			
RADIATION ENVIRONMENT																			
ORBIT CONTAMINATION																			
ATMOSPHERE MODEL																■			
ORBIT DECAY																			
ORBIT MANEUVER																			
ORBIT ERROR ANALYSIS																	■		
MISSION CONSUMABLES								■											
ORBITER ATTITUDE MANAGEMENT					■														
INSTRUMENT POINTING										■									
MISSION TIMELINE GENERATION																			
EXPERIMENT DATA PROCESSING																			
ORBIT EPHEMERIS/TIMELINE PLANNING						■													
CONTINGENCY OPERATIONS PLANNING																			
SUBSYSTEM PERFORMANCE MONITOR																			
GROUND TRUTH COORDINATION CONTROL																			
PAYLOAD (EXPERIMENTS) STATUS MONITOR																			
THERMAL ANALYSIS																			
ELECTRICAL POWER ANALYSIS																			
DATA MANAGEMENT																			
STABILIZATION AND CONTROL																			
BOOST TRAJECTORY ANALYSIS																			
ENTRY TRAJECTORY ANALYSIS																			
TERMINAL TRAJECTORY ANALYSIS																			
BOOST PERFORMANCE ANALYSIS																			
SUBSATELLITE MOTION ANALYSIS																		■	
MASS PROPERTIES AND ANALYSIS									■										
LOADS/STRESS ANALYSIS																			

Figure 5.1-5. Ground Processing Software Availability (JSC)

TASK	PROGRAM		S* W**	EXPERIMENT GROUPINGS	SYSTEM/PROGRAM COST ANALYSIS	GROUND-TRACE GENERATOR	TARGET-OPPORTUNITY GENERATOR	COMMUNICATIONS COVERAGE	SOLAR/MISSION GEOMETRY	RADIATION ENVIRONMENT	ORBIT CONTAMINATION	ATMOSPHERIC MODEL(S)	ORBIT DECAY	ORBIT MANEUVERS	ORBIT ERROR ANALYSIS	SUBSATELLITE MOTION ANALYSIS	MISSION CONSUMABLES	ORBIT ATTITUDE ANALYSIS	INSTRUMENT POINTING	MISSION TIMELINE GENERATION	EXPERIMENT DATA PROCESSING	ORBIT EPHEM/TIMELINE UPDATE	CONTINGENCY OPS PLANNING	SUBSYSTEM PERFORM. MONITOR	GROUND TRUTH COORD CONTROL	PL (EXPMTS) STATUS MONITOR	THERMAL ANALYSIS	MASS PROPERTIES & ANALYSIS	LOADS/STRESS ANALYSIS	ELEC PWR ANALY & REQMTS	DATA MANAGEMENT ANALYSIS	STABILIZ & CONTROL ANALYSIS	UNKNOWN CORRELATION
				5	2	3	5	5	3	2	5.5	2.8	3	5	4	1.2	3.5	2	3.5	6	100	3	5	2.5	8	5	3	5	5	5	4	5	-
ORBIT/LAUNCH TIME/DATE SELECTION — EARTH OBSERVATIONS/ AMPS/SOLAR	WORLD MAP	WMAP	38			X																			X								
	ORBITAL TRACK OPTIMIZATION	OTO	35				X																										
	PERCENT AREA COVERAGE EARTH RESOURCES	PACER	29				X																										
	PHASING	PHASE	25											X																			
	RAPID OPERATION FOR MISSION PLANNING	ROMP	25				X							X											X								
	GROUND LIGHTING ORBIT ORIENTATION	OLOO	25						X																								
	TIME OF ASCENDING AND DESCENDING SITE OBSER-VATION	TADSO	18				X																		X								
	AMPS MISSION SIMULATOR	AMS	27																														X
ORBIT/LAUNCH TIME/DATE SELECTION — ASTRONOMY	ASTRONOMY	ASTRON	38						X																								
	LAUNCH TIME	LANTIM	22						X																								
	AVERAGE VIEWING TIME	AVTIM	38				X																										
	PSEUDO STRAY LIGHT ISOCHRONAL CONTOUR	PSLIC	31				X		X									X				X											
	CONTINUOUS SUN LAUNCH TIME	CONSULT	15						X																								
	STRAY LIGHT AND VISING EVALUATOR	SLAVE	25				X		X													X											
TARGET OPPORTUNITIES	SITS ACQUISTION AND LOSS	SAL	31				X															X			X								
	EPHEMERIS GENERATOR FOR ORBITAL EVALUATOR	EGORE	32			X	X	X	X	X												X	X		X								
	AUTOMATIC SPACECRAFT OCCULATION ROUTINE	ASOR	28					X																									
	SENSOR TARGET OCCULATION PROGRAM	STOP	32					X										X	X			X	X								X		
	(SLAVE)	(SLAVE)	25				X		X													X											
	(PSEUDO STRAY LIGHT ISOCHRONAL CONTOUR)	(PSLIC)	31				X		X													X											
ORBIT CHARACTERISTICS/ ENVIRONMENT	ANALYTIC SATELLITE EPHERMERIS PROGRAM	ASEP	32				X		X			X		X				X				X	X										
	ORBITAL LIFETIME	LIFTIM	32									X	X			X																	
	RELATIVE MOTION	REL	17													X																	
	RADIATION MODEL	RADI	30							X																							
	RADIATION CALCULATION	RADCAL								X																							
	ORBIT ENVIRONMENT SUMMARY	OES	30			X	X	X		X																							
	CLOUD MODEL	CLOUD	30									X										X			X								
	ATTENUATION MODEL	ATTEN	25				X					X													X								
SHUTTLE PERFOR-MANCE	INSERTION SURFACE	INFACE	22																														
	INTEGRATED MISSION PROGRAM	IMP	32											X			X																
	PERFORMANCE CALCULATIONS	PERCAL	25														X																
	DEBOOST OPPORTUNITY PROGRAM	DEBOP	26																	X			X										
PAYLOAD ACTIVITY SCHEDULING	SOLAR PHYSICS AND EARTH RES EXP SCHEDULER	SPERES	32	X																X		X			X					X			
	STELLAR TARGET SCHEDULER	SCREAM	32	X																X		X								X			
	AMPS MISSION SCHEDULER	AMPS	-	X																X		X								X			
	CREW TIMELINE	CREWTL	24	X																X		X											
	GENERAL ACTIVITY SCHEDULER	WAMPUM	22	X													X			X		X		X	X	X				X			
	TIMELINE INTEGRATOR	TINT	48	X													X			X		X		X	X	X				X			
	MISSION OPERATIONS SEQUENCE SUMMARY	MOSS	15											X					X	X													
	DATA STORAGE PROFILE	DASPRO	32	X				X													X	X		X							X		
	ATTITUDE TIMELINE INTEGRATOR	ATINT	38	X										X				X	X			X											
	FLIGHT PLAN SUMMARY	FPS	24					X		X				X			X			X				X									
SYSTEM/ SUB-SYSTEM ANALYSIS	GRAPHICS LAYOUT	AIDS	32	X																								X					
	MASS PROPERTIES	MASS	25	X													X											X					
	SHUTTLE PAYLOAD INTERFACE LOADS	SPIL	3	X																									X				
	THERMAL MODAL NETWORKS ANALYSIS	STINDA	45																					X			X						
	THERMAL RADIATION ANALYSIS	TRASYS	45	X														X				X					X						
	POINTING CONTROL SIMUATION	IPS	20																X					X									
	SPACELAB CONTAMINATION MODEL	CONTAM	53	X							X																						
	UNKNOWN CORRELATION				X																											X	

Table header: ROCKWELL - DEFINED FUNCTIONS (columns) / MSFC PROGRAMS (rows)

*S STATEMENTS (K)
**W WORDS (K)

Figure 5.1-6. Ground Processing Software Availability (MSFC)

6.0 GROUND PROCESSING IMPLEMENTATION COST FACTORS

There are two conventional approaches by which the user can obtain the identified services: the historical approach is batch processing, and a more recent approach is toward time-sharing, using a remote terminal. A third approach is to provide dedicated mini-computers. The remote terminal and dedicated mini-computer approaches are classed as interactive because the user and the associated computer program interact in a conversational mode to select and initialize the process and deliver the results. All three approaches were examined for cost factors.

All processing begins by the user identifying the initialization data and the program(s) to be used; see Figure 6.0-1. In the interactive approach the user enters the initialization data on a typewriter-like keyboard as the computer program drives a CRT. A conversation between user and program leads him step by step through the proper sequence of data entry. In the batch approach the user enters the parameters on a standard form sheet; this is translated by a programmer into FORTRAN control cards and data cards. The result of the process is a printout that is delivered to the user for evaluation.

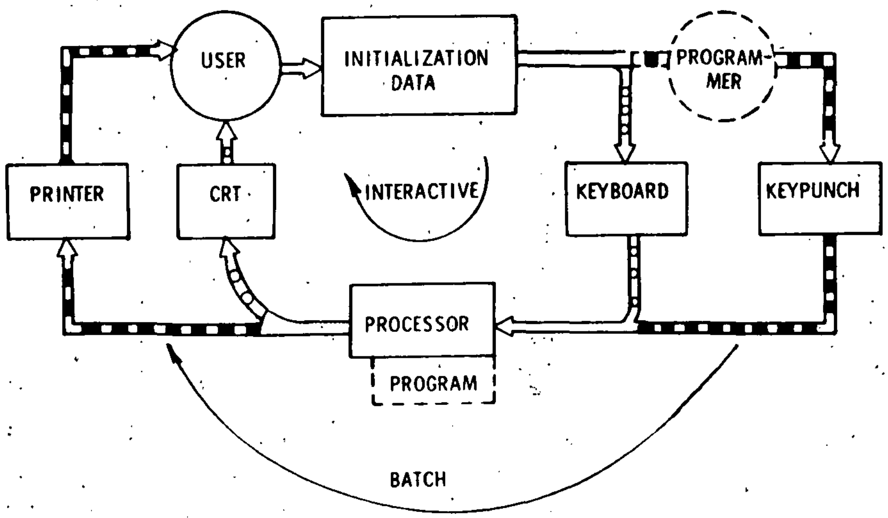


Figure 6.0-1. Interactive/Automatic (Batch) Concept

Figure 6.0-2 illustrates the user interface with the processing system. The left side of the figure shows a CRT display for the interactive approach; the right side of the figure represents the standard form sheet for the batch approach. The same data are entered in both cases. In the interactive approach, all the tutorial information is within the display. The user, using a typewriter keyboard, calls for a specific program; the tutorial program responds with questions and any restrictions on input. The user types in responses and is led step by step through the correct process to initialize the program. In the batch approach, a separate user programming manual would provide the instructions.

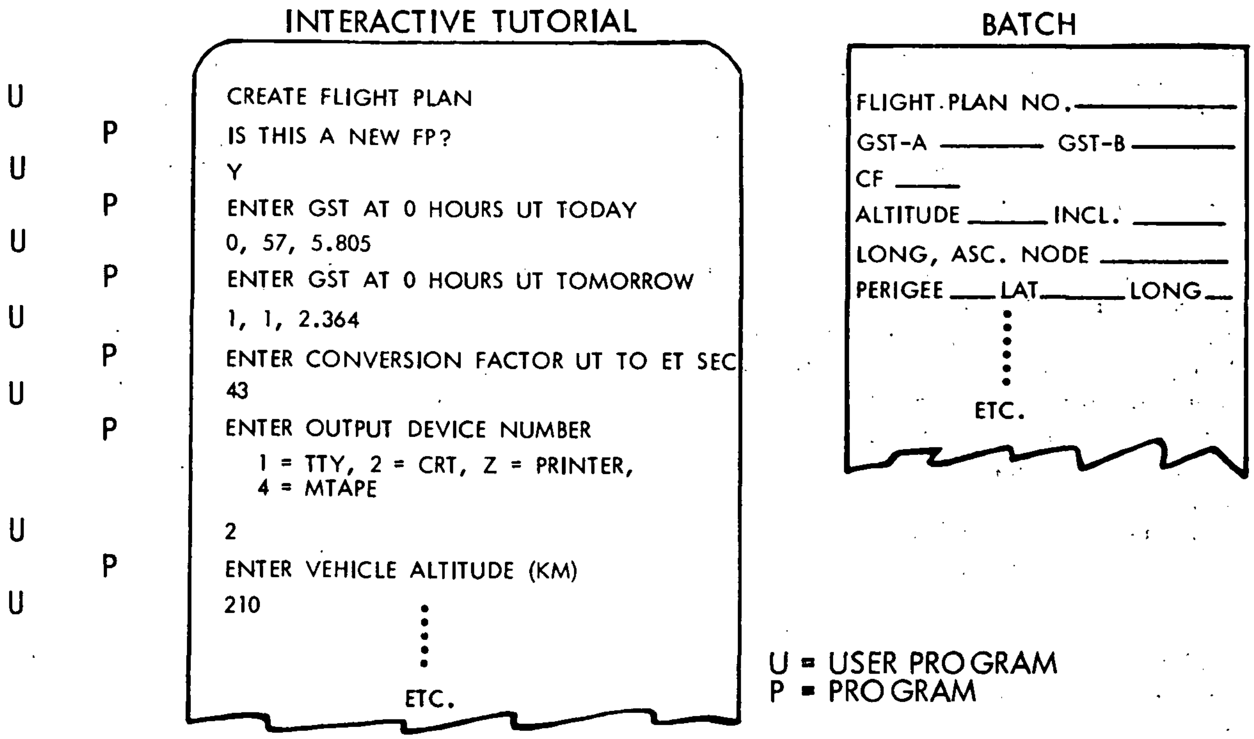


Figure 6.0-2. Ground Processing Tutorial Requirements

Table 6.0-1 indicates some of the factors to be considered in evaluating the batch processing approach.

Table 6.0-1. Batch Processing Considerations

- ESSENTIAL PROGRAMS: 29
- OPTIONAL PROGRAMS: 5
- ESTIMATED AVERAGE RUNS PER FLIGHT: 20 TIMES EACH

  34 x 20 = 680 RUNS

- PROGRAMMING TEAM

  1 LEAD PROGRAM ANALYST @ $50K/YEAR
  1 CODER (KEYPUNCH OPERATOR) @ $40K/YEAR

- ESTIMATED RUN RATE PER TEAM: 4/DAY

  680 ÷ 4 = 170 DAYS/FLIGHT

  $(50K + 40K) \times \frac{170}{250} = \$61.2K/FLIGHT$ (250 WORKING DAYS PER MAN-YEAR)

- TURNAROUND TIME PER RUN

  LOCAL: 1 WORKING DAY

  REMOTE: 3 WORKING DAYS (NASA SPEC. HANDLING)
  10 WORKING DAYS (U.S. POSTAL SERVICE)

Twenty-nine essential programs and five optional programs were identified. Based upon Rockwell experience with similar processes it is estimated that an average of 20 *runs* will be made for each program for each flight. The batch approach requires the support of a separate programmer to establish the program control parameters, and a coder to keypunch the data cards. Rockwell experience also indicates that one team could handle an average of four different runs per day. For any flight rate exceeding one/year, more than one team would be needed.

Batch processing is the conventional approach to obtain services from a large data processing center. However, the turnaround time from user's initial request to the delivery of the printout is the major reason for avoiding the batch approach. (For the interactive approach, turnaround time is in minutes and the user can rapidly make modifications to optimize his results.) The batch approach was necessary to utilize large computers efficiently to service many diverse customers in an era when hardware installation cost far exceeded the salaries of a few programmers. Due to technology improvements in hardware this relationship has been transposed so that the personnel costs (software) now exceed the hardware costs.

A modern approach was developed whereby a number of individuals could address the computer system directly in real-time by employing a remote terminal consisting of a keyboard and a printer, or CRT display. This approach was possible because the computer is so fast that each individual appeared to have immediate access. A large improvement in user convenience was made by developing tutorial interactive programs.

Implementation of the interactive approach requires the availability of a software system designed to support it. Figure 6.0-3 illustrates the process needed for a ground software support system (GS^3). The basic source programs (GS^3 tutorial) are assumed to be available in a program file. The tutorial program links the input requirements of the source program into conversational requirements of the user and, together, the source application program is generated. The source application program is compiled, edited, and then executed; the results are displayed on the CRT and recorded on a printer.

MSFC has developed the GS^3 with the tutorial feature, and has implemented it for their 1108 computer, is converting it to run on an S/360 computer, and has run some of the programs on a mini-computer (PDP 11/45). To convert the MSFC GS^3 to operate with local mini-computers may require some modification to the software: (1) the programs may need to be translated to be recompiled for the selected local mini-computers, and (2) the programs may need to be converted to operate with a disc or tape mass memory system. It is estimated, as a worst case, that about $700K would be the cost for such modification.

The interactive approach can be implemented using a large-scale data processing center coupled to remote terminals. Two alternatives are shown in Figure 6.0-4. The data processing center (DPC) may be local (at Langley) or remote (perhaps at MSFC or KSC). If remote, the coupling would be via dataphone digital service, elements of which are shown. Dataphone digital service is offered at only a limited number of major switching centers and does not generally go to local exchanges. Special terminal sets are required to couple to the switching centers, differing slightly for different distances to the user site. Charges are both fixed-monthly and mileage-related.

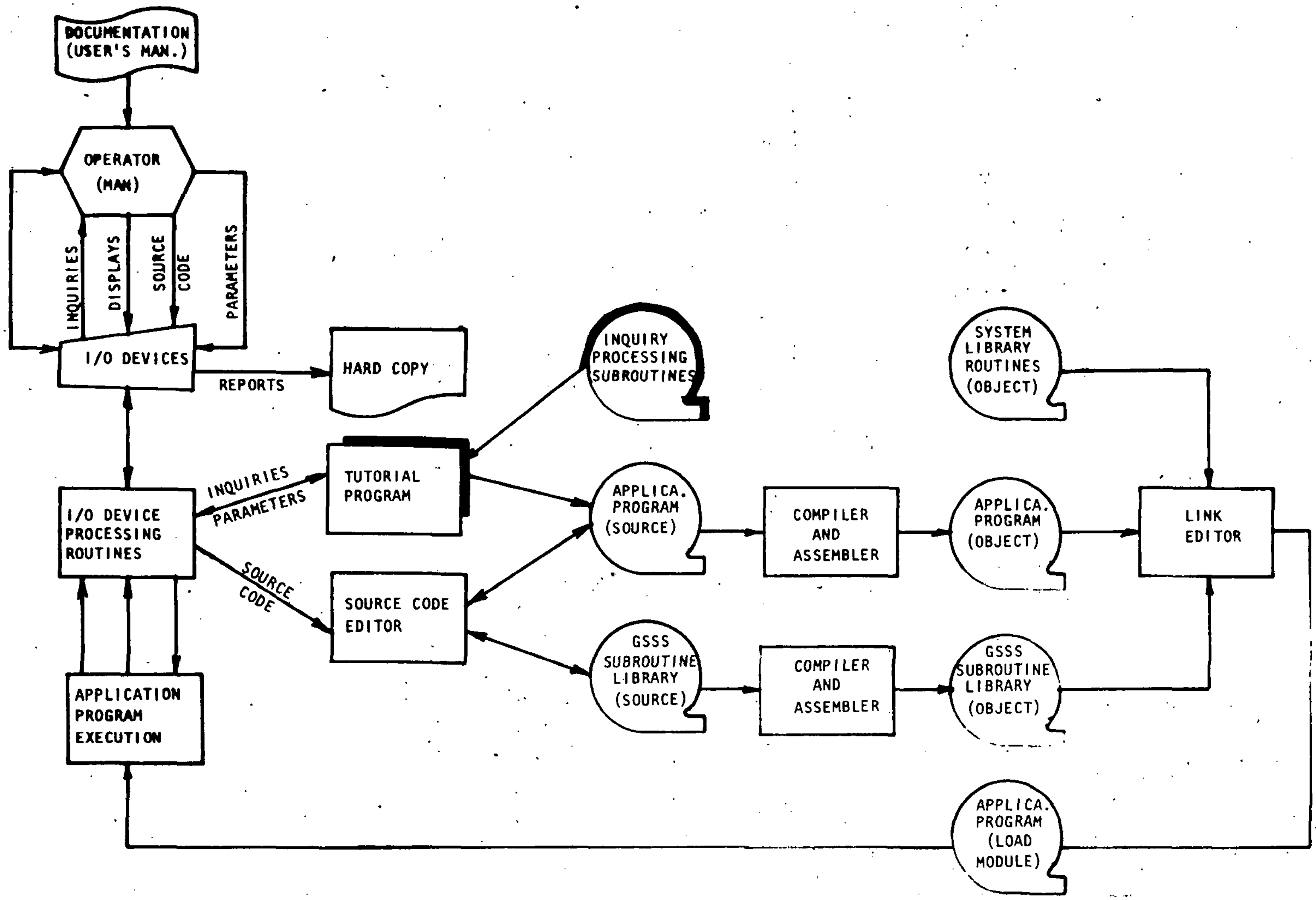


Figure 6.0-3. Ground Software Support System

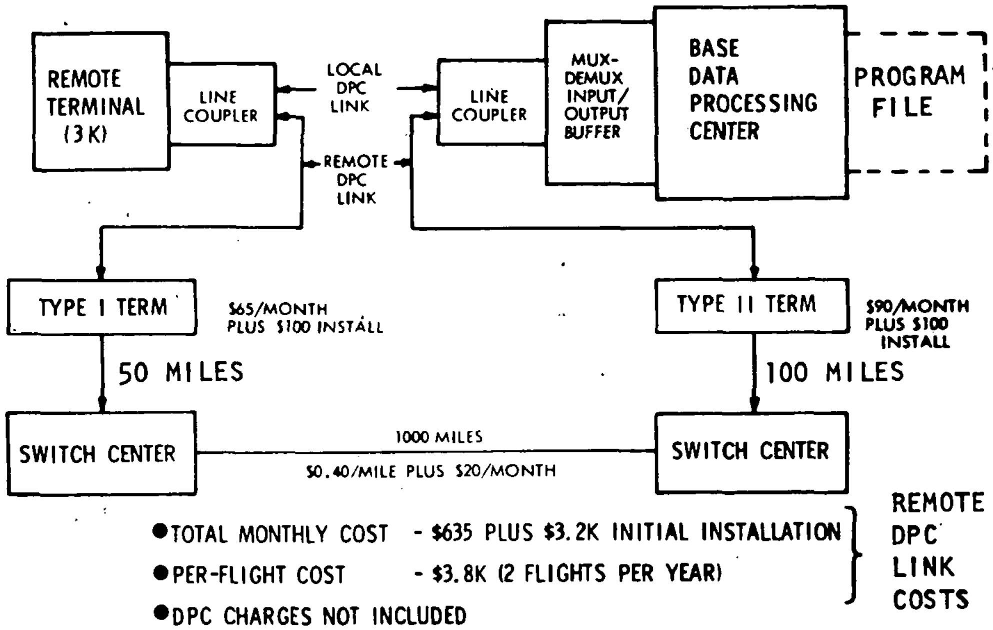


Figure 6.0-4. Remote Terminal Alternatives

All implementation approaches that would time-share a large computer at a data processing center incur run-time costs. Using the same factors as for batch processing (see Table 6.0-1), the cost of utilization of the data processing center can be estimated as shown in Table 6.0-2. Rockwell experience indicates that the average run time for programs of this complexity would be about 5 minutes. For all runs the total time per flight is then 57 hours. Rockwell's IBM/370 time rate is $375/hour, giving a cost/flight of $21,000.

Table 6.0-2. DPC Utilization/Rate Estimates

• ESSENTIAL PROGRAMS: 29 • OPTIONAL PROGRAMS: 5	• DPC UTILIZATION RATE: 5.7% (2 FLIGHTS/YEAR)
• AVG DPC CLOCK TIME/RUN: 5 MIN.	• EST COST @ $375/HR = $21K/FLT
• EST AVG RUNS/FLT: 20 (6-MO. CYCLE) 34 X 5 X 20 = 3400 MINUTES OR 57 HR/FLT	• DOES NOT INCLUDE EXPERIMENT DATA REDUCTION

As stated previously, technology improvements have drastically lowered the cost of computer hardware. For about $40,000, a mini-computer system complete with remote terminals, printers, etc., can be procured.

The mini-computer has the same computational capability and equivalent speed as the large center computer. The mini-computer operates on one program at a time and does not time-share its capability with many user programs. The interactive approach can be implemented using dedicated mini-computers. Three configurations, shown in Figure 6.0-5, were developed, defined, and sized to provide the capability to support the ground processing requirements. A mini-set is an intelligent terminal and mini-computer, is the same for all versions and is based upon the same mini-computer model defined for the preparation of the flight applications software (Section 3.0) and described in detail in the appendix. The only difference between the three options is the method of providing an expanded memory capacity for program storage. Option I would utilize a disc memory (15 megabytes) that would be time-shared by several mini-sets. Option II would utilize a number of tape cartridges, which could be shared between several mini-sets, but not simultaneously. Option III would also utilize a disc memory but it would not be shared with other mini-sets.

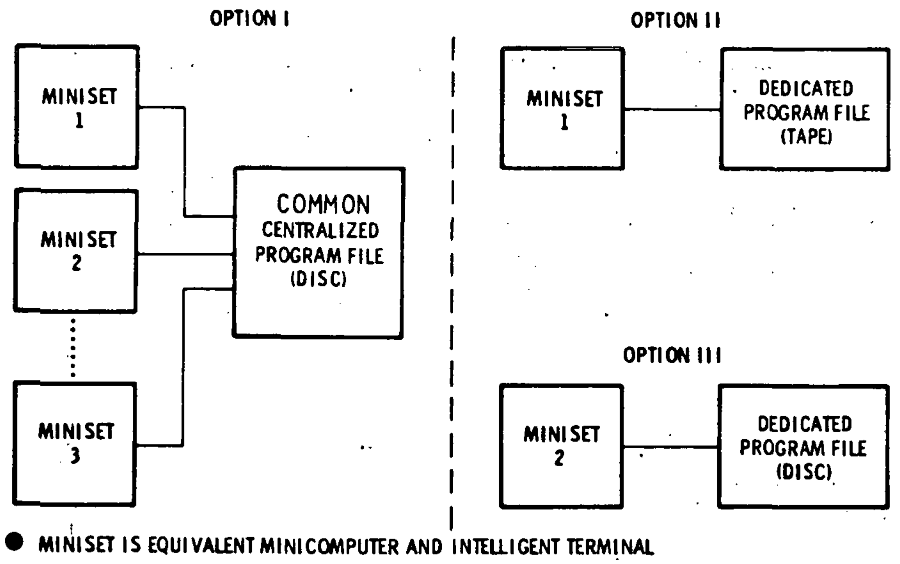


Figure 6.0-5. Mini-Processor Alternatives

Table 6.0-3 lists the hardware elements needed to provide the desired capability for the three mini-computer approaches.

Table 6.0-3. Mini-Processor Cost Analysis (1975 Dollars)

		UNIT COST	MINI COMMON DISC	MINI DEDICATED TAPE	MINI DEDICATED DISC
HP 2112A	MAIN FRAME	6,200			
HP 2102A-001	DUAL-CH PORT CONTROLLER	750			
HP 2102A	MAIN MEMORY CONTROLLER	500			
AVC DI-112	RECORDER, SINGLE	1,835			
HP 2102A-003	MEMORY PROTECT SYSTEM	500			
HP 12944A	POWER FAIL RECOVERY	475	$ 18.0 K	$ 18.0 K	$ 18.0 K
HP-12880	DISPLAY TERM ADAPTER	570			
HP 12531	TELETYPE I/O CARD	570			
AVC DI-112	RECORDER I/O CARD	1,600			
HP 2640A	DISPLAY TERMINAL	3,000			
HP 2752A	TELETYPE TERMINAL	2,000			
AVC DI-112	RECORDER, DUAL	3,400		$ 3.4 K	
HP 2102A-008	8K X 16-BIT MEMORY MOD	1,500	$ 12.0 K	$ 12.0 K	$ 3.0 K
-	DISC MEMORY SET	16,000	$ 16.0 K		$ 16.0 K
		TOTAL	$ 46.0 K	$ 33.4	$ 37.0K

The several cost elements were assembled for the six approaches for implementation. The ATL baseline traffic model was used to spread these costs over the proposed 10-year program. The rules used to assemble cost data for the six approaches are as follows:

1. One remote terminal will be needed for each flight per year.

2. One miniset will be needed for each flight per year.

3. All concepts using a central data processor are charged $21,000 per flight.

4. For the batch approach, $61,000/flight is charged for program analyst/coder salary.

The matrix, Table 6.0-4, indicates the elements that are needed for each concept.

Table 6.0-4. Cost-Estimating Elements

	RT	M	DPC	DDS	PROG
RT TO LOCAL	✓		✓		
RT TO KSC	✓		✓	✓	
BATCH			✓		✓
MINI TAPE		✓			
MINI COM DISC		✓			
MINI DISC		✓			

RT • REMOTE TERMINAL
M • MINI-COMPUTER
DPC • DATA PROCESSING CENTER
DDS • DATAPHONE DIGITAL SERVICE
PROG • PROGRAMMER/COMPUTER ENGINEER

Table 6.0-5 summarizes the annual expenditures, both non-recurring and sustaining, to provide the desired capability. As expected, the batch approach is the most expensive as well as the least convenient. The difference between the local and remote approaches is due to the digital dataphone service costs.

Table 6.0-5. Implementation Cost Comparison

YEAR OF FLIGHT	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	
NO. OF FLIGHTS		1	1	2	3	3	3	4	4	4	5	5	PROGRAM TOTAL
BATCH[1,2] (NON-TUTORIAL)	82	82	164	246	246	246	328	328	328	410	410	-	\$2870K (\$82K/FLIGHT)
REMOTE TERMINAL TO LOCAL DPC[2,3]	* 24	21	* 45	* 66	63	63	* 87	84	84	* 108	105	-	\$750K (\$15K NON-RECURRING) (\$21K/FLIGHT)
REMOTE TERMINAL TO REMOTE DPC[2,3,4]	* 32	29	* 53	* 74	71	71	* 95	92	92	* 116	113	-	\$838K (\$15K NON-RECURRING) (\$29K/FLIGHT)
MINI-COMMON DISC[5]	* 46	-	* 30	* 30	-	-	* 30	-	-	* 30	-	-	\$166K
MINI-DEDICATED TAPE[5]	* 33	-	* 33	* 33	-	-	* 33	-	-	* 33			\$165K
MINI-DEDICATED DISC[5]	* 37	-	* 37	* 37	-	-	* 37	-	-	* 37	-	-	\$185K

[1]PROGRAMMER TEAM, SALARY PER FLIGHT AT \$61K.

[2]ALL CONCEPTS USING DPC CHARGED \$21K PER FLIGHT (57 HOURS OF RUN TIME X \$375).

[3]ONE REMOTE TERMINAL PER FLIGHT PER YEAR AT \$3K.

[4]DATAPHONE DIGITAL SERVICE CHARGE AT \$635/MONTH.

[5]ONE MINI SET PER FLIGHT PER YEAR.

*REQUIRED CAPITAL INVESTMENT/EQUIPMENT PURCHASE.

7.0 PROGRAMMATIC EVALUATION

Based upon the data, analyses and rationale of the previous sections, an integrated approach to implement and support the Langley ATL missions was selected. The selected approach is described separately for the on-board processing, including command and control, and the ground processing. The various cost elements to support these approaches are then accumulated and presented as annual funding requirements. Data sheets and specifications for the hardware and software elements are provided in a subsequent appendix for reference.

7.1 ON-BOARD PROCESSING RECOMMENDATIONS

Evaluation of the data presented in Section 4.4 indicates that the dedicated mini/micro processor approach with intelligent terminals as a common work station is preferable. The recommended integrated flight configuration is as shown in Figure 4.2-2. Each PI (with the support of a programmer) would be responsible for the preparation of the software for his dedicated mini/micro processors using his flight hardware in a test configuration. The flight software support system (FSSS) would be used as the primary *tool* in the software preparation. Figure 3.1-8 indicated the approach for preparation of experiment flight software.

Concurrent with the on-site software/hardware development, test, and validation, the users would provide requirements for the Spacelab central processing system in terms of measurement lists, telemetry lists, caution/warning list, annotation requirements, and mission timelines. These would be integrated by the Spacelab Level III manager and prepared for incorporation into the CDMS.

Experiment command and control would use the intelligent terminal, with the computer-aided procedures listings, supplemented by certain *emergency* hardwired displays and controls. The PI would provide the computer hardware and prepare the software for those functions of his experiment that require computer support.

The PI is not constrained in his selection of computer hardware or method of software preparation, nor to the use of the intelligent terminal as a work station. There are, however, a number of interface control constraints that must be followed if his experiment is to be integrated within a Spacelab mission. Each mini/micro processor, for example, must include a standard hardware and software interface to the CDMS system. Each processor must also include a standard interface to the intelligent terminals if used as a shared work station.

To achieve maximum benefit for the PI with this approach, the FSSS should be developed as a standard programming tool. The design of the FSSS should be such that it is applicable to a variety of mini/micro processors, and not limited to a specific computer model or manufacturer.

7.2 GROUND PROCESSING RECOMMENDATIONS

The evaluation of ground processing approaches indicates a distinct advantage for the dedicated mini-set concept, both in lower program costs and in convenience and turnaround time. The recommended configuration is the mini-disc approach (Table 6.0-3).

Figure 5.1-6 listed the programs being developed by MSFC and indicates a good correlation as to what was identified as essential program capabilities. Investigation of program compatibility (S/360-FORTRAN to mini-FORTRAN) indicates that with relatively minor compiler modification and editing of the FORTRAN program listing, a program written for an S/360 can be run on a mini-processor.

All of the MSFC programs include the tutorial algorithms so that individuals untrained in programming skills may use them with some orientation. There remains the effort to select a specific mini-processor, and the software elements needed to utilize the programs. Cost estimates were provided, but recommendations for acquisition are considered outside the scope of this study.

7.3 INTEGRATION, TEST AND OPERATIONS

The implementation concepts for integration, test and operations defined in the SUIAS report were reviewed. No inconsistencies were found in respect to the ATL requirements other than reducing the workload of the payload integration activity. This is the result of distributing processors, most of the software development, and most of the software integration to the individual user-PI. The payload integration function remains, but at a reduced level of effort.

Tests during development (Level IV) and rack/pallet assembly (Level III), as in SUIAS, require the participation of the PI and the selected payload specialist flight crew. Crew training may be somewhat less by virtue of a common man-machine interface format (intelligent terminal).

In SUIAS, operations during the flight included a capability to monitor progress with a mini-control room. Critical evaluation of the referenced ATL payload experiments did not indicate a user requirement for real-time replanning of the flight timeline. Without such a requirement it is difficult to justify a need for extensive facilities--particularly automated facilities. Voice and television with (perhaps) a global ground track display and an occasional *snapshot* of required data (primarily for troubleshooting malfunctions) appear to be adequate. Real-time scientific data evaluation was not required; permanent records (tape or film) of flight operations for post-flight evaluation was the primary requirement. Thus, no attempt was made to mechanize a mini-control room utilizing mini-processors, large computers, or any facilities other than those identified in the SUIAS report.

7.4 ATL PROGRAMMATIC PAYLOAD MODEL

Only three ATL reference payloads were specified. These payloads indicated the use of multiple Spacelab configurations, significant variations in on-board manual operations, and experiment reflights. In order to develop programmatic costs, a representative ATL payload traffic model was formulated.

In Section 3.0, a representative complement of hardware/software for the required on-board computer services was derived based upon the three reference ATL payloads. It was assumed that a typical ATL payload would require 6 mini-processors, 14 micro-processors, and 2500 statements of mission-unique flight applications software. However, the total number of experiments in the reference payloads were 11, 11, and 12. Therefore, control panel and computer-aided command/control equipment and software requirements were derived to reflect the total complement of experiments on an ATL payload.

In terms of command/control functions, analyses of all 25 reference ATL experiments indicated that not all of them could or would be controlled from a common work station. The experiments were categorized into four groups according to their complexity of manned operations and man-machine interface characteristics (see Table 7.4-1). The experiments in Group 1 required extensive command/control/monitor operations. Although the experiments in Group 2 were highly automated, a significant man-machine control/monitor interface was still required. The experiments in Group 3 required only initiate/terminate control actions. The Group 4 experiments required direct man-participation involving manual dexterity and/or visual acuity.

Table 7.4-1. Man-Machine Interface Grouping

GROUP 1	EXTENSIVE CONTROL & MONITOR REQUIRED	
	• NV-1 MICROWAVE INTERFEROMETER	• EO-5 LASER RANGING & ALTIMETRY
	• NV-2 AUTONOMOUS NAVIGATION	• EO-6 MICROWAVE LATIMETER
	• NV-3 MULTIPATH MEASUREMENTS	• EO-7 SEARCH & RESCUE AIDS
	• EO-2 TUNABLE LASERS	• EO-8 IMAGING RADAR
	• EO-4 MICROWAVE RADIOMETER	• EO-9 RF NOISE MEASUREMENT
GROUP 2	HIGHLY AUTOMATED BUT EXTENSIVE MONITORING/EVALUATION REQUIRED	
	• EO-1 LIDAR MEASUREMENTS	
	• EO-3 MULTISPECTRAL SCANNER	
	• PH-4 NEUTRAL GAS PARAMETERS	
GROUP 3	HIGHLY AUTOMATED, ONLY INITIATE/TERMINATE ACTIONS REQUIRED	
	• PH-6 METEOR SPECTROSCOPY	• CS-2 ZERO-G STEAM GENERATOR
	• MB-1 COLONY GROWTH	• CS-X CONTAMINATION MONITOR
	• EN-3 NON-METALLIC MATERIALS	
GROUP 4	DIRECT MAN PARTICIPATION, DEXTERITY, VISUAL ACUITY REQUIRED	
	• PH-2 BARIUM CLOUD RELEASE	• MB-4 BIOCELL ELECTRICAL CHAR.
	• PH-3 AEROSOL OPTICAL PROPERTIES	• MB-5 BIOCELL SPECIAL PROPERTIES
	• MB-2 MICRO-ORGANISM TRANSFER	• EN-5 MICRO-ORGANISM SAMPLING
	• MB-3 BIOCELL ELECTRICAL FIELD OPACITY	

The operational characteristics of the first two groups of experiments are readily adaptable to the computer-aided command/control approach. The fourth group of experiments are not adaptable to the computer-aided approach. Although the third group of experiments could be adapted to the computer-aided approach the control actions are simple, non-repetitive, and require minimal monitoring; this group is not recommended for computer-aided command/control implementation.

Re-examination of the reference ATL payloads indicates that the experiments in Groups 1 and 2 correlate with those for which dedicated mini-processors for the on-board services were identified. Thus, it was postulated that six experiments of the nominal payload would include the computer-aided command/control concept.

As the average number of experiments in the reference ATL payloads was 11, an allowance for hardwired control panels was also made. Several of the experiments in Groups 3 and 4 pertain to microbiology and require either no controls or minimal controls. In order to reflect the averaging effect of this class of experiments it was postulated that four hardwired control panels would be required for each ATL payload and would cost approximately $3K each. (The average panel cost if all controls were hardwired was derived in Section 4.1, and was $5K.)

Based upon the previously defined typical ATL payload, flight and ground hardware and software programmatic cost factors were derived. Hardware requirements are summarized in Figure 7.4-1. The display terminals and printers that are allocated to the PI's are for development/validation of software. Two additional display terminals were allocated to the lead center and would be the actual common-work-station flight hardware. The remote activation systems are associated with the six experiments that would utilize the computer-aided command/control approach. The mini-disc sets are allocated to the lead center to support the mission planning activities.

ATL REPRESENTATIVE PAYLOAD - 10 EXPERIMENTS

PI ALLOCATION		LEAD CENTER ALLOCATION	
• MINI-PROCESSOR SYSTEMS		• MINI-DISC SETS	
• 6 MINI-PROCESSORS	$ 168 K	• 2 MINI-PROCESSOR	$ 31 K
• 6 DISPLAY TERMINALS	$ 18 K	• 2 DISPLAY TERMINAL	$ 6 K
• 6 PRINTERS	$ 12 K	• 2 PRINTER	$ 4 K
• 14 MICRO-PROCESSORS	$ 154 K	• 2 DISC MEMORY	$ 32 K
• COMMAND/CONTROL DEVICES		• FLIGHT COMMAND/CONTROL	
• 6 REMOTE ACTIVATION SYS.	$ 3.6 K	• 2 DISPLAY TERMINALS	$ 6 K
• 4 CMD/CONTROL PANELS	$ 12 K		
SUPPORTS 2 FLIGHTS PER YEAR			

➡ FLIGHT HARDWARE

Figure 7.4-1. Programmatic Hardware Complement

Software cost factors are summarized in Figure 7.4-2. The recurring costs include the preparation of the flight applications software for both the mini- and micro-processors for all the experiments on a payload. Command/control services reflect the use of the computer-aided approach in the mechanization of six experiments. The CDMS services are associated with the integration of telemetry, caution and warning, data annotation, and mission timelines with the Spacelab and Orbiter.

RECURRING ON-BOARD SERVICES (PER PAYLOAD)		NON-RECURRING SOFTWARE DEVELOPMENT TOOLS	
MANDATORY COMPUTER SERVICES		FLIGHT SOFTWARE SUPPORT SYSTEM	$ 680 K
2500 STATEMENTS @ $31/	$ 77.5 K		(1)
COMMAND/CONTROL SERVICES		COMMAND/CONTROL DELTA TO FSSS	
1200 STATEMENTS @ $31/	$ 37.2 K	1200 STATEMENTS @ $62/	$74.4 K
72K BYTES (DATA TABLES) @ $.01/	$ 0.7 K		
CDMS SERVICES		GROUND SOFTWARE SUPPORT SYSTEM DELTA	
300K BYTES (DATA TABLES) @ $.01/	$ 3.0 K		$700 K
3 HR HOST MACHINE TIME @ $375/	$ 1.1 K		
3 MAN-MO. INTEGRATION	$ 12.5 K		(2)

(1) AGENCY DEVELOPMENT

(2) WORST CASE ESTIMATE; COMPLETION OF MSFC PROJECT COULD ALMOST ELIMINATE THIS ITEM.

Figure 7.4-2. Software Programmatic Complement

Non-recurring software costs are for the development of the basic FSSS and the delta to the FSSS to efficiently utilize the computer-aided command/control approach, and to convert/modify existing/in-work mission planning software at MSFC to Langley's specific use. Because of the broad application of the FSSS it is recommended that its development be sponsored by the agency --not uniquely attributed to ATL. Upon completion of the GS^3 work at MSFC this software development tool may also be directly applicable to ATL payloads. A worst case assumption was made in the development of ATL programmatic costs; all non-recurring software development was assessed to the ATL program.

In order to develop programmatic costs it was necessary to establish guidelines for ATL flight rates and reflight commonality for both hardware and software. Figure 7.4-3 summarizes the selected guidelines. Three ATL traffic models were used: the baseline (*Yardley* traffic model), maximum of 2 flights/year, and a one-flight-per-year program.

As panels, actuator hardware, and micro-processors are an integral part of the experiment equipment, sharing of these end items between experiments was not considered to be practical. However, experiment reflights are anticipated. Thus, it was assumed that the reuse of this type of hardware would average 40 percent during the course of the ATL program. Mini-processors are *stand-alone* end items and can be shared between experiments. Thus 100-percent reuse was assumed. Each mini-processor can support two flights per year.

• TRAFFIC MODELS

YEAR →	81	82	83	84	85	86	87	88	89	90	91
• BASELINE	1	1	2	3	3	3	4	4	4	5	5
• 2 FLT/YEAR LIMIT	1	1	2	2	2	2	2	2	2	2	2
• 1 FLT/YEAR LIMIT	1	1	1	1	1	1	1	1	1	1	1

• HARDWARE REUSE

- PANELS 40%
- ACTUATORS 40%
- MICRO-PROCESSORS 40%
- MINI-PROCESSORS 100%

4 OF 10 EXPERIMENTS REFLOWN (PANELS, ACTUATORS, MICRO-PROCESSORS)

SHARED UP TO 2 FLIGHTS/YEAR (MINI-PROCESSORS)

• SOFTWARE REUSE

- MINI-MICRO SOFTWARE - 25% (ON-BOARD SERVICES AND COMMAND/CONTROL)
- CDMS - 0% (NEW EACH FLIGHT)

Figure 7.4-3. Programmatic Costing Criteria

The FSSS is the primary element of reusable software; this reuse was the driving factor in the derivation of the concept. In addition, it is anticipated that a limited amount of mission-unique software will be applicable for reuse on reflights. A 25-percent software reuse factor was estimated. As the experiment mix of each ATL payload is different, the CDMS/experiment integration effort will be significantly different each flight. It was assumed that this integration effort ($16.6K per flight) would be required for each flight.

7.5 PROGRAMMATIC COST SUMMARIES

Based upon the cost factors and reuse criteria presented in the previous section, a compilation of the programmatic software-related costs for each ATL traffic model is presented in Tables 7.5-1 (baseline), 7.5-2 (2 per year), and 7.5-3 (1 per year). Cumulative recurring costs (basic FSSS, command/control delta, and GSSS mods not included) are plotted for the three traffic models in Figure 7.5-1. The software-related per-flight costs are slightly more than $200K. The minor per-flight variations between traffic models are due to different utilization rates of the mini- and micro-processors and the intelligent terminals.

Table 7.5-1. Program Cost Summary - Baseline ATL Traffic Model ($K)

	YEAR OF FLIGHT	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
	NO. OF FLIGHTS				1	1	2	3	3	3	4	4	4	5	5
ON-BOARD PROCESSING	ON-BOARD HARDWARE														
	MINI-PROCESSORS			168			168						168		
	MICRO-PROCESSORS			154	92	185	277	277	277	370	370	370	462	462	
	ACTIVATION SYSTEMS			4	2	5	7	7	7	10	10	10	12	12	
	CONTROL PANELS			12	7	14	22	22	22	29	29	29	36	35	
	INTELLIGENT TERMINALS			6			6						6		
	ON-BOARD SOFTWARE														
	MANDATORY			78	47	94	140	140	140	187	187	187	234	234	
	COMMAND/CONTROL			38	23	46	68	68	68	91	91	91	114	114	
	CDMS			17	17	34	51	51	51	68	68	68	85	85	
	TOTAL			477	188	378	739	565	565	755	755	755	1117	943	
	SUPPORT HARDWARE														
	DISPLAY TERMINAL - PRINTERS			30			30						30		
	SUPPORT SOFTWARE														
	FSSS BASIC	300	300												
	FS3 CMD/CONT DELTA		75												
	TOTAL	300	375	30			30						30		
GROUND PROCESSING	MINI-DISC SETS			37		37	37			37			37		
	GSSS MODIFICATIONS	250	250	200											
	TOTAL	250	250	237		37	37			37			37		
	COMPOSITE TOTALS	550	625	744	188	415	806	565	565	792	755	755	1184	943	

Table 7.5-2. Program Cost Summary - 2 Flights/Year Limit ($K)

	YEAR OF FLIGHT	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
	NO. OF FLIGHTS				1	1	2	2	2	2	2	2	2	2	2
ON-BOARD PROCESSING	ON-BOARD HARDWARE														
	MINI-COMPUTERS			168											
	MICRO-COMPUTERS			154	92	185	185	185	185	185	185	185	185	185	
	ACTIVATION SYSTEMS			4	2	5	5	5	5	5	5	5	5	5	
	CONTROL PANELS			12	7	14	14	14	14	14	14	14	14	14	
	INTELLIGENT TERMINALS			6											
	ON-BOARD SOFTWARE														
	MANDATORY			78	47	94	94	94	94	94	94	94	94	94	
	COMMAND/CONTROL			38	23	46	46	46	46	46	46	46	46	46	
	CDMS			17	17	34	34	34	34	34	34	34	34	34	
	TOTAL			477	188	378	378	378	378	378	378	378	378	378	
	SUPPORT HARDWARE														
	DISPLAY TERMINAL - PRINTER			30											
	SUPPORT SOFTWARE														
	FS^3 BASIC	300	300												
	FS^3 CMD/CONT DELTA		75												
	TOTAL	300	375	30											
GROUND PROCESSING	MINI-DISC SETS			37		37									
	GSSS MODIFICATIONS	250	250	200											
	TOTAL	250	250	237											
	COMPOSITE TOTALS	550	625	744	188	415	378	378	378	378	378	378	378	378	

Table 7.5-3. Program Cost Summary - 1 Flight/Year Limit ($K)

	YEAR OF FLIGHT	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
	NO. OF FLIGHTS				1	1	1	1	1	1	1	1	1	1	1
ON-BOARD PROCESSING	ON-BOARD HARDWARE														
	MINI-COMPUTERS			168											
	MICRO-COMPUTERS			154	92	92	92	92	92	92	92	92	92	92	
	ACTIVATION SYSTEMS			4	2	2	2	2	2	2	2	2	2	2	
	CONTROL PANELS			12	7	7	7	7	7	7	7	7	7	7	
	INTELLIGENT TERMINALS			6											
	ON-BOARD SOFTWARE														
	MANDATORY			78	47	47	47	47	47	47	47	47	47	47	
	COMMAND/CONTROL			38	23	23	23	23	23	23	23	23	23	23	
	CDMS			17	17	17	17	17	17	17	17	17	17	17	
	TOTAL			477	188	188	188	188	188	188	188	188	188	188	
	SUPPORT HARDWARE														
	DISPLAY TERMINAL - PRINTER			30											
	SUPPORT SOFTWARE														
	FSSS BASIC	300	300												
	FS^3 CMD/CONT DELTA		75												
	TOTAL	300	375	30											
GROUND PROCESSING	MINI-DISC SETS			37											
	GSSS MODIFICATIONS	250	250	200											
	TOTAL	250	250	237											
	COMPOSITE TOTALS	550	625	744	188	188	188	188	188	188	188	188	188	188	

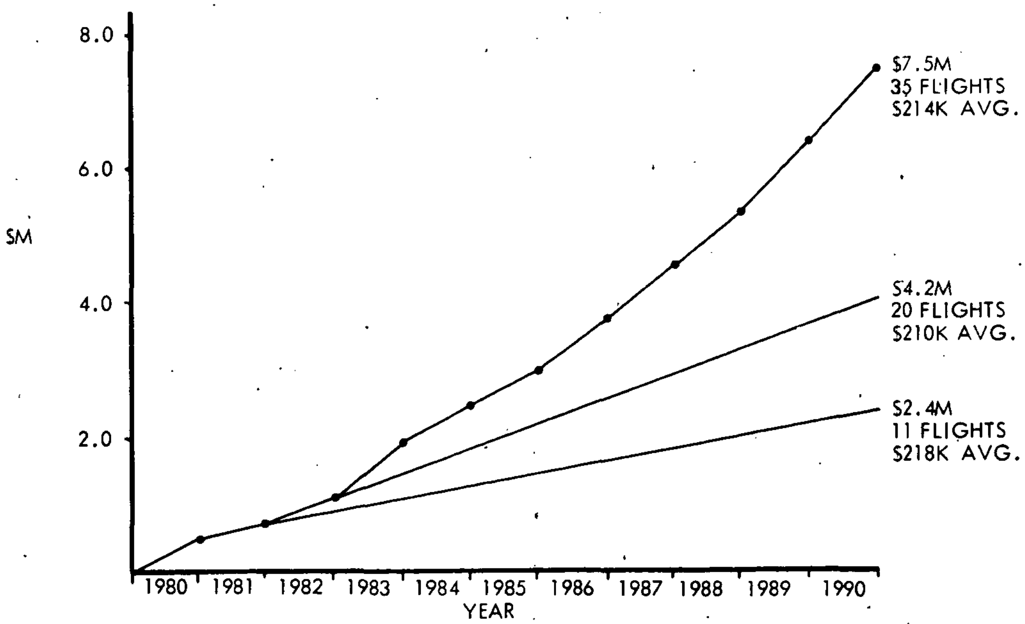


Figure 7.5-1. Cumulative Recurring Cost Summaries

7.6 RECOMMENDATIONS AND CONTINGENCY EVALUATION

The results of the analyses and projections of programmatic costs indicate that the mini/micro processor approach for required on-board computer services will efficiently provide more autonomy and convenience to the PI's and be less costly than the centralized approach. Computer-aided command and control is recommended for those experiments requiring significant man-machine interfaces. Use of the processors for the on-board services facilitates the implementation of the computer-aided implementation. The computer-aided approach cannot be used for all experiments since some are (by their nature) inoperative from a central/common work station. Because of the limited payload panel space in the Orbiter aft-flight-deck a corollary recommendation to the computer-aided approach is to maximize those experiments that can utilize the computer-aided command/control approach on pallet-only payloads.

Comparison of alternate approaches for accomplishing mission planning/integration tasks indicates that the use of a mini-computer system with tutorial software is significantly less costly than either batch or remote terminal processing. The added convenience and flexibility of a dedicated mini-disc configuration results in the recommendation of this particular mini-computer system.

These recommendations are based upon the assumption that both the FSSS and GSSS will be developed. A contingency evaluation was conducted to determine the impact of no FSSS and no conversion/adaptation of the MSFC GSSS to Langley's specific computers. (The MSFC GSSS will be accessible via remote terminal.) The basic recommendations, contingency evaluation, and required additional effort are summarized in Table 7.6-1.

Without the FSSS the PI must develop his flight applications software, including all the library routines, independently. This effort will increase the quantity of required on-board services software for each mission by about 9600 statements. However, without the FSSS the computer-aided command/control approach would be impractical to implement, and the computer-aided software (1200 statements) would not be developed. Thus, the net increase in software would be 8400 statements. Assuming adequate programmer support is available for working directly with the PI (informal relationship/minimal documentation) these additional statements will cost $31 each and add $260K to the cost of experiment software.

Even if the problems/complexity/costs associated with the required integration of control panels for the pallet-only configuration are neglected, the hardware costs will increase without the computer-aided approach. With the FSSS (and computer-aided approach) $16K of the hardware costs was for activation system hardware and simple control panels ($352K was for processors). Without the FSSS all experiments will require hardwired panels at an average cost of $5K/experiment or $50K/payload. Therefore, the total software development and related hardware costs for the first ATL payload will be $293K greater without the FSSS than with the FSSS. If the same software and hardware reuse criteria were used for the ATL traffic model without the FSSS, the delta programmatic costs after four flights would be greater than the development costs of the FSSS.

Table 7.6-1. Program Recommendations

RECOMMENDATIONS

MAXIMIZE USE OF DEDICATED (MINI/MICRO) PROCESSORS

USE COMPUTER-AIDED COMMAND/CONTROL APPROACH FOR EXPERIMENTS WITH EXTENSIVE MAN/MACHINE INTERFACE

USE MINI-DISC APPROACH FOR GROUND OPERATIONS

CONTINGENCY EVALUATION (FIRST FLIGHT ONLY)

<table>
<tr><th></th><th colspan="2">FIRST FLIGHT COSTS</th><th></th></tr>
<tr><th></th><th>WITHOUT FSSS</th><th>WITH FSSS</th><th>COMMENTS</th></tr>
<tr><td>ON-BOARD OPS</td><td>• MINI/MICRO S/W $ 375 K
• CDMS SOFTWARE 17 K
• PI HARDWARE 402 K
• LEAD CENTER HDW 6 K
TOTAL $ 800 K</td><td>• MINI/MICRO S/W $ 116 K
• CDMS SOFTWARE 17 K
• PI HARDWARE 368 K
• LEAD CENTER HDW 6 K
TOTAL $ 507 K</td><td>• FSSS = $755K
• SAVINGS USING FSSS FOR 3-4 FLIGHTS EQUALS FSSS COSTS</td></tr>
<tr><th></th><th>WITHOUT LOCAL GSSS</th><th>WITH LOCAL GSSS</th><td rowspan="2">• GSSS IMPLEMENTATION IS NOT TIME-CRITICAL
• ONLY PROGRAMMATICS FAVOR MINI-DISC APPROACH</td></tr>
<tr><td>GROUND OPERATIONS</td><td>• REMOTE TERMINAL $ 32 K</td><td>• MINI-DISC APPROACH $ 37</td></tr>
</table>

REQUIRED ADDITIONAL EFFORT

FLIGHT OPERATIONS SOFTWARE

- DEVELOPMENT OF FSSS FOR ON-BOARD SERVICES
- DEVELOPMENT OF DELTA FSSS FOR COMMAND/CONTROL FUNCTIONS
- DEFINITIZATION OF CDMS/DEDICATED PROCESSOR INTERFACES
- DEMONSTRATION OF DEDICATED PROCESSOR APPROACH & INTEGRATION

GROUND OPERATIONS SOFTWARE

- ANALYSIS/EVALUATION OF CURRENT TUTORIAL GSSS FOR LANGLEY PAYLOADS
- ADAPTATION OF CURRENT GSSS TO MINI-PROCESSORS

Implementation of a local GSSS capability with the mini-disc computer system is not time-critical. Use of a remote terminal approach results in, essentially, a recurring $32K/flight cost; the mini-disc approach is a non-recurring capital investment of $37K.

It is recognized that the preferred approaches for ATL flight and ground operations software are contingent upon two key software development tools--the FSSS and the GSSS. Because of the repetitive nature of ATL Spacelab flights, as well as other Spacelab payloads, a significant programmatic cost savings can be achieved if software reuse is maximized. It is believed that the proposed/conceptually defined FSSS will facilitate the reuse of on-board software as well as expedite the preparation of mission-unique software. A more detailed definition and synthesis of the primary elements of the FSSS, coupled with a demonstration with representative payload equipment, should be accomplished before a Spacelab programmatic commitment is made. It is recommended that such an activity be initiated within this calendar year in order to support the initial Spacelab flights in a timely manner.

The additions to the basic FSSS for command/control by an interactive display terminal is also recommended. Pallet-only configurations are frequent. With the limited panel space for payloads in the Orbiter, experiment grouping flexibility will be constrained unless shared intelligent terminals are viable. It should be emphasized that unless the basic FSSS is provided, the computer-aided approach for command and control is not recommended. Without the FSSS tutorial feature, each PI/user would be forced to prepare this software using more conventional methods, or use the CDMS capability. Use of the CDMS would, of course, recentralize a major effort with an attendant increase in costs.

A conceptual CDMS-dedicated processor interface was defined. As both the Spacelab and ATL payloads are at the hardware development stage, a definitized interface (signal characteristics, coding, timing, etc.) should be established. This proposed effort consists basically of analyzing the specific characteristics of the CDMS and the Spacelab data bus and determining the interface requirements/specifications that a dedicated processor must meet. This analysis is not recommended until after the critical design review on the CDMS later this year.

The current GSSS development at MSFC was primarily for remote terminal applications. A detailed analysis of the MSFC programs is required to determine the potential extent of modifications to MSFC programs for use on dedicated mini-processors. As the MSFC program is still in progress, a preliminary activity to convert the programs to at least one mini-processor is underway, and a commitment to a local GSSS is not time-critical, this effort can be postponed for at least another year.

8.0 PALLET-ONLY CONFIGURATION SPECIAL CONSIDERATIONS

In general, the analyses and trades of alternate mechanizations of on-board operations were conducted without consideration of the specific Spacelab configuration involved. If the pallet-only configuration is uniquely considered the recommendation for implementation of the computer-aided command/control approach is not only cost-effective, but mandatory, because of limited panel space in the Orbiter aft-flight-deck (AFD).

The baseline *payload* panel allocation in the Orbiter AFD is illustrated in Figure 8.0-1. This area must be shared by the Spacelab (subsystem controls) and the experiments. The baseline panel space allocation for operation of Spacelab systems utilizes 1432 in^2 of the 3200 in^2 (shaded area) available for Orbiter payloads. Thus, only the cross-hatched area (1768 in^2) is available for ATL experiment control panels.

Table 8.0-1 summarizes the required dedicated command/control panel areas for the experiments of the reference pallet-only ATL payload. In addition, dedicated displays (spectrum analyzers, oscilloscopes, etc.) are required by several of the ATL experiments and are also indicated in the table. Even if the TV monitors (see Figure 8.0-1) are shared between experiment, Spacelab, and Orbiter operations, the dedicated displays/monitors increase the required ATL AFD panel area to 2161 in^2, which obviously exceeds the available space. By adopting the computer-aided command/control approach for the first seven ATL experiments listed in Table 8.0-1 (which is in accordance with the recommendations in Section 7.5), the required AFD panel space would be reduced by 950 in^2. Making an allowance of 342 in^2 for a dedicated intelligent terminal for experiment operations would result in a total ATL experiment panel requirement of 1563 in^2, which is compatible with the available space.

In this analysis, only total panel areas were considered, and the available ATL panel space was marginal even with the computer-aided approach. Actual panel layouts and consideration of potential interference between top-mounted and front-mounted panels due to the depth dimensions of the equipments will reduce, if not eliminate, the accommodation margin. Thus, in actual practice it may be necessary to (1) implement the computer-aided approach in more of the experiments and/or (2) limit the experiments on pallet-only Spacelabs to those that are compatible with the computer-aided approach.

A cost analysis of the two command/control approaches for the reference ATL pallet-only payload was conducted (Table 8.0-2). Panel costs were extracted from Table 4.1-5. In addition to the panels for the last five experiments listed in Table 8.0-2, actuation hardware ($600/experiment) is required for the seven experiments that incorporate the computer-aided approach. Software and data tables for the seven applicable experiments will result in an additional $44K expenditure for the computer-aided approach. The cost difference of about $15K corresponds quite well with the predicted differences for typical ATL experiments. The nominal cost difference between the computer-aided and hardwired approaches was about $2K/experiment (Figure 4.4-1).

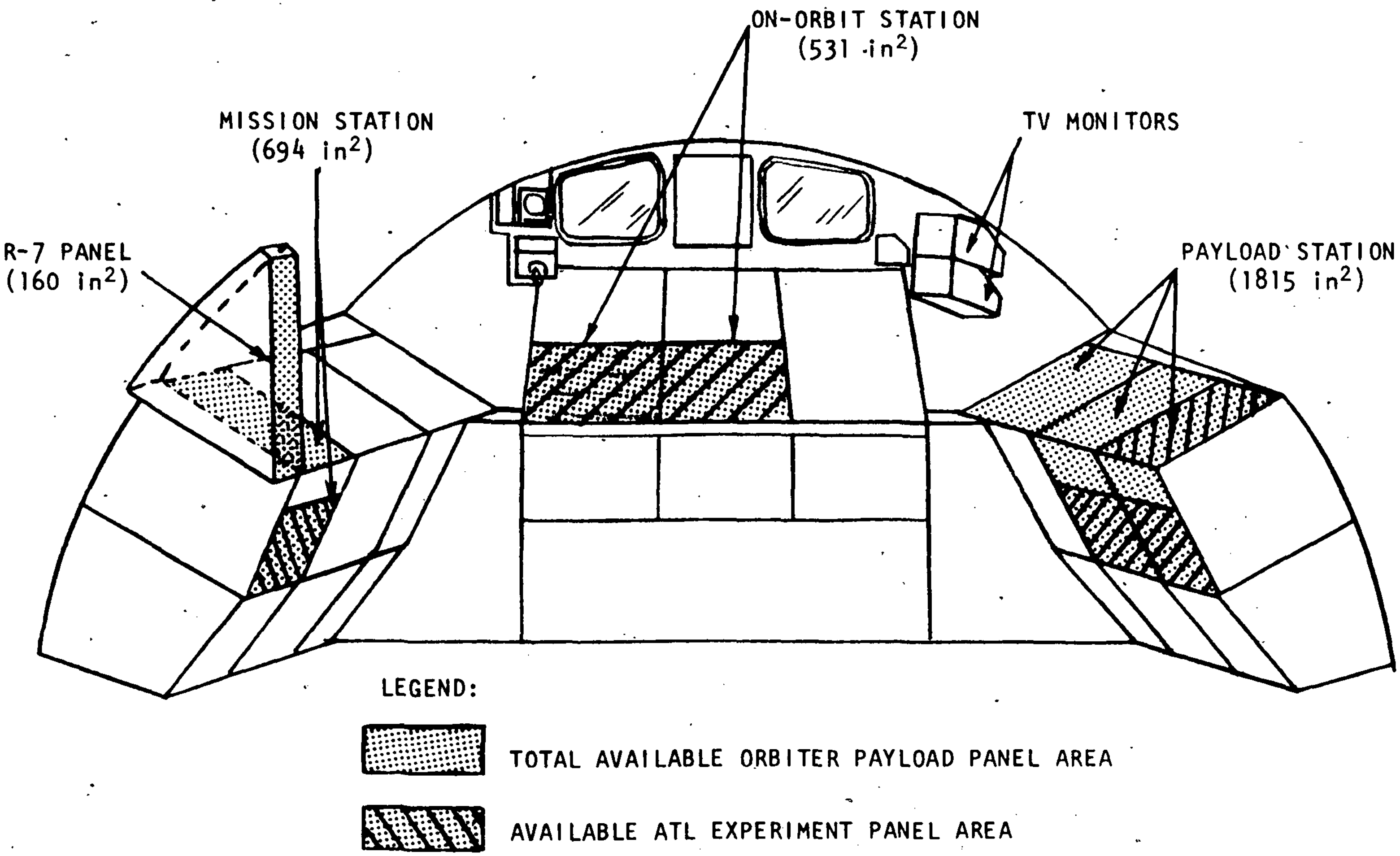


Figure 8.0-1. AFD Panel Allocation for Orbiter Payloads

Space Division
Rockwell International

Table 8.0-1. ATL Pallet-Only Payload-Required Hardwired Panel Space (Thousands of Dollars)

	EXPERIMENT		COMMAND/ CONTROL AREA (IN^2)	TV MONITOR	DEDICATED DISPLAY AREA (IN^2)
EXTENSIVE COMMAND, CONTROL, & MONITOR REQUIRED	NV-1	MICROWAVE INTERFEROMETER	95	*	
	NV-2	AUTONOMOUS NAVIGATION	171	*	152
	EO-4	RADIOMETER	209	*	152
	EO-7/8	SEARCH & RESCUE/IMAGING RADAR	209	*	152
	EO-1	LIDAR MEASUREMENT	133	*	152
	PH-4	NEUTRAL GAS PARAMETERS	133		152
MANUAL DEXTERITY & VISUAL ACUITY REQUIRED	PH-6	METEOR SPECTROSCOPY	95		
	EN-3	NON-METALLIC MATERIALS	133		
	CS-X	CONTAMINATION MONITOR	133		
	PH-2	BARIUM CLOUD RELEASE	247	*	
	EN-1	MICRO-ORGANISM SAMPLES	95		
		TOTAL	1653	*	508

*SHARE TV WITH SPACELAB AND ORBITER OPERATIONS.

Table 8.0-2. Cost Comparison of Command/Control Approaches for Reference Pallet-Only ATL Payload

EXPERIMENTS	HARDWIRED APPROACH	COMPUTER-AIDED APPROACH	
	PANELS	HARDWARE	SOFTWARE
NV-1	2.8		
NV-2	5.3		
EO-4	7.0		
EO-7/8	7.0	4.2	44.1
EO-1	7.0		
PH-4	4.2		
PH-6	4.0		
EN-3	2.2		
CS-X	3.7	24.7	-
PH-2	12.1		
EN-1	2.7		
	57.9	73.0	

It is believed that the delta cost for implementing the computer-aided approach is warranted because (1) dedicated hardwired panels for a pallet-only payload are not viable; (2) costs associated with integration of multiple experiment panel requirements would far exceed the $15K, and (3) the computer-aided approach permits PI autonomy and flexibility. Consideration of the pallet-only payload not only substantiates the computer-aided recommendations, it makes the approach highly desirable if not mandatory.

9.0 GUIDELINES FOR THE USE AND IMPLEMENTATION OF SOFTWARE

Throughout the analyses the primary objectives have been to maintain autonomy of individual experiments, maximize hardware and software reuse, and minimize programmatic costs. The results not only reflect these factors but also indicate that they are compatible. In this section, guidelines for the development of ATL payloads that will assist in the achievement of these objectives are delineated.

9.1 FLIGHT OPERATIONS CONSIDERATIONS

Develop the Basic Flight Software Support System. Analyses indicate that for a continuing program such as the ATL, significant cost savings can be realized if a software development *tool* is used. The proposed concept will minimize the mission-unique software that is required.

Maximize the Use of On-Board Experiment-Dedicated Mini/Micro Processors. The cost savings in software development that can be achieved if dedicated processors are used warrants the slight weight, power, volume, and costs of these processors. The PI's autonomy and flexibility of design and operations are also maximized with dedicated processors.

Develop the Delta FSSS for Command/Control Functions. Although the computer-aided approach is slightly more costly than the hardwired approach the Orbiter AFD panel constraints (pallet-only Spacelab configuration) will not accommodate a completely hardwired concept. Development of computer-aided software and hardware on an individual experimenter basis would be costly and inefficient.

When Feasible, Implement the Computer-Aided Command/Control Approach. The reflight nature of the ATL program indicates that even if experiments are initially scheduled for the habitable-module Spacelab configuration, they may be subsequently scheduled for a pallet-only flight. Because of the AFD panel constraints a hardwired panel used in the habitable module may not be usable in the AFD. Thus, a second development would be required. Initial development of the computer-aided approach for command/control functions would provide the PI and Langley the maximum flexibility in payload grouping/flight scheduling. Also, the computer-aided approach is more adaptable to changes than the hardwired approach. With the evolving technology associated with ATL experiments, flexibility of design is extremely important.

9.2 GROUND OPERATIONS CONSIDERATIONS

Implement the GSSS. The consideration of the number of times that mission planning analyses must be performed and the duration of the ATL program make it almost imperative that a tutorial software *tool* be utilized. Batch processing is not only cumbersome and frustrating, it is also costly. In this study only the payload integrator was considered in the mission planning phase. However, each PI must also do individual mission planning analyses that pertain to his experiment. Current PI's may have the necessary software programs, but during the course of the ATL program it is doubtful if more than a small percentage of the PI's will be so equipped. Implementation of a tutorial GSSS approach will facilitate the participation of a broad segment of the scientific community and minimize the affect of personnel turnover in the payload integrator's organization.

Adopt the Mini-Disc Mission Analysis Approach. Although the remote terminal approach will suffice the convenience, flexibility and programmatic costs warrant the mini-disc approach. This dedicated processor approach becomes highly desirable when the PI's are considered. Again, if a broad segment of the scientific community is to participate in the ATL program, techniques to minimize the costs of the individual PI's and maximize the accessibility to data banks must be implemented. For example, providing a remote terminal link between a PI at the University of South Dakota and a central computer at Langley is unrealistic. Except for the disc-memory device this PI's dedicated processor would suffice. Disc-memory devices could be shared between PI's in the same manner as the proposed sharing of dedicated mini-processors. (Note: disc-memory devices for individual PI's were not included in the cost analyses of this study.)

9.3 DESIGN CONSIDERATIONS

As both the Spacelab hardware and Spacelab operations are in a design/development stage, specific design requirements for ATL payloads are not identifiable at this time. However, the following guidelines indicate the types of design requirements that will have to be met. In some cases "TBD's" are noted because of insufficient design definition at this time.

1. All potential hazards due to experiment operations or to credible failures of experiment equipment will be redundantly instrumented; these instrument signals, properly conditioned, will be direct-wired to the Spacelab and Orbiter caution/warning system. The PI will be required to demonstrate to a safety review board the adequacy of his analysis and design to avoid or contain any hazard or hazardous condition due to his equipment or its operation.

2. Experiment-derived data that will be telemetered to ground via the Orbiter avionics system will be acquired, formatted, and annotated within the experiment system prior to transmission under control of the Spacelab CDMS.

3. Experiment-derived data to be sampled and converted by an RAU shall have the following electrical characteristics: (TBD).

4. Experiment-derived data to be transferred via the MUX shall have the following electrical characteristics: (TBD).

5. Experiment-derived data that are to be displayed via the CDMS CRT will be described by a document similar to that illustrated by Table 4.2-2.

6. Experiment remote-control actions that are to be initiated via the CDMS keyboard will be described by a document similar to that illustrated by Table 4.2-4.

7. The PI shall provide the interface hardware within his equipment to decode and interpret command signals from the CDMS RAU.

8. The experiment-RAU interface hardware shall have the following characteristics: (TBD).

9. The CDMS will provide Orbiter-derived annotation data (time, position, attitude) on a periodic basis, via the data bus/RAU network. The PI shall provide the interface hardware to accept and process these digital signals within his equipment.

10. The CDMS will provide annotation data at (TBD) intervals, in the following format: (TBD).

11. The experiment interface hardware to process the annotation data shall have the following electrical characteristics: (TBD).

*12. The PI should consider a computer-aided implementation of command/control when the operator's procedures are complex and sensitive to proper sequencing.

*13. The PI should consider a computer-aided implementation of command/control when the experiment system is remotely located from the operator's work station (specifically for pallet-only missions).

14. The PI should consider an automated approach of implementing control for (a) emergency sequences, (b) time-critical operations, (c) repetitive sequences where the operator's judgment is not required, and (d) operator reaction time may be exceeded. (NOTE: *Automatic* control may utilize a mini/micro computer, but more generally would be implemented by clocked timer-sequencers or other mechanical devices--particularly (a) and (c)--or by sensor *trigger* mechanisms such as limit switches or optical detectors.)

*15. The PI should consider a hardwired approach for implementing control if (a) the experiment equipment requires no in-flight mechanical or procedural adjustments, or (b) the operator's participation is limited to initiating/terminating automatic sequences.

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*These guidelines should be considered in conjunction with Flight Operations Considerations--*When Feasible, Implement the Computer-Aided Command/Control Approach.*

APPENDIX

HARDWARE/SOFTWARE REFERENCE DATA

APPENDIX

HARDWARE/SOFTWARE REFERENCE DATA

This appendix includes descriptive data of the hardware and software elements synthesized in this study. In Section A, the flight and ground processor systems are presented. The software programs associated with on-board computer services and the FSSS are discussed in Section B. Abbreviated software program descriptor sheets for the GSSS are presented in Section C.

SECTION A. HARDWARE CONFIGURATIONS

The several mini-computer-based configurations that have been evolved to support all ATL processing requirements are accumulated in this appendix. These are followed by descriptive data on each component. Although the data are related to a specific processing system (Hewlett-Packard 2100), this should not be interpreted as a selection or recommendation to Langley; the data are indicative of the generic requirements. It is recommended that an impartial evaluation of available mini-processor hardware be instituted to selected standard sources for procurement.

Figure A-1 presents the micro-computer configuration for flight hardware. It is intended to be an integral part of the experiment hardware, and nominally to perform only one service for that experiment. All components are mounted on standard printed circuit boards, and are off-the-shelf items, except for one special bus interface adapter (BIA). The BIA card is a hardware assembly that electrically matches the CDMS data bus and MUX. A one-time development of approximately $3K is required.

Normally, only one software program would reside in this computer, permanently recorded in the programmable read-only memory (PROM). This programming may be done with the mini-computer test set (available at the lead center) and by using the manufacturer's facilities (cost about $250/PROM to *burn in* the chip), or by purchasing the related chip burn-in machine from the manufacturer (cost about $4000).

Micro-processor system costs are itemized in Table A-1. Equipment descriptor sheets for the major components are also included.

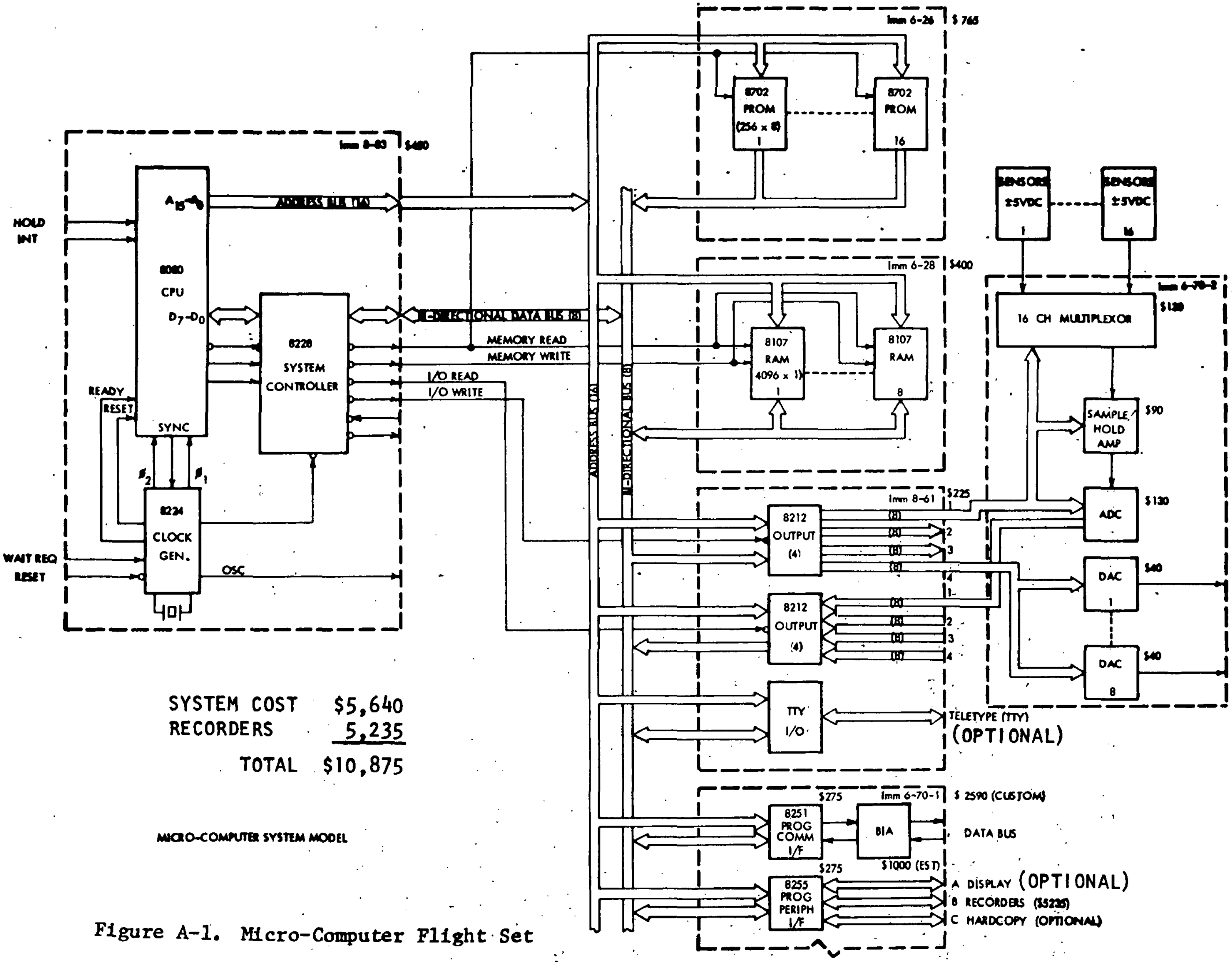

Figure A-1. Micro-Computer Flight Set

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Table A-1. Micro-Processor System Complement

				$	
MICRO-COMPUTER					
1 mm 8-83	Central Processor Module	1 ea.		450	
1 mm 8-61	Input/Output Module	1 ea.		225	
1 mm 6-26	PROM Memory Module and	1 ea.		125	
	C8702A PROM Chips @ $40	16 ea.		640	
1 mm 6-28	RAM Memory - 4K x 8 Static	1 ea.		400	
1 mm 6-70-1	Universal Prototype Module	2 ea.	40		
	P8251 Programmable Comm. I/F	1 ea.	275		
	P8255 Programmable Periph. I/F	1 ea.	275	2,590	
	Bus I/F Adapter (Estimate)	1 ea.	1,000		
	Module Design/Assembly	1 ea.	1,000		
1 mm 6-70-2	Universal Prototype Module	2 ea.	40		
	DATEL mm-16 Multiplexer	1 ea.	130		
	DATEL ADC-EH8B2 A/D Converter	1 ea.	130	1,210	
	DATEL SNM-2 Sample/Hold Amplifier	1 ea.	90		
	DATEL DAC-9 Digital/Analog Conv.	1 ea.	320		
	Module Design/Assembly	1 ea.	500		
				5,640	
RECORDERS					
AVC D1-112	Dual			3,400	
AVC D1-112	Single			1,835	
				5,235	
					10,875

OPTIONAL EQUIPMENT

Teletype-Hardcopy Printer	$2000
Display Terminal	$1000

CENTRAL PROCESSOR MODULE

Complete 8-bit parallel central processor module with system clocks, interface and control for memory, input/output ports, and real-time interrupt.

SPECIFICATIONS

WORD SIZE
Instruction: 8, 16, or 24-bits
Data: 8-bits

CENTRAL PROCESSOR
8080 CPU, 8-bit accumulator, six 8-bit registers, subroutine nesting to any level, multiple level interrupt capability, asynchronous operation with memory

INSTRUCTION SET
78 including conditional branching, binary arithmetic, logical operations, register-to-register transfers, and I/O instructions

MEMORY ADDRESSING
Any combination of PROM, ROM, and RAM up to 65,536 bytes

MEMORY INTERFACING
Address: 16-bits TTL compatible
Input Data: 8-bit TTL compatible
Output Data: 8-bit TTL compatible

I/O ADDRESSING
Input: 256 8-bit input ports
Output: 256 8-bit latching output ports

I/O INTERFACE
Input Data: 8-bit TTL compatible
Interrupt Data: 8-bit TTL compatible
Output Data: 8-bit TTL compatible
One 8-bit local output port implemented as output port FF

SYSTEM CLOCK
Crystal controlled, 2 MHz ±0.01%
Processor cycle time: 500 ns

CONNECTORS
Edge Connector: Dual 50-pin PC connector on 125 mil centers. Connectors in rack must be positioned on 500 mil centers minimum
P/N C800100 from SAE
P/N VPB01C50E00A1 from CDC

PHYSICAL CHARACTERISTICS
Width 0.062 in. (1.57 mm)
Height 6.18 in. (157 mm)
Depth 8.00 in. (203 mm)
Weight 8 oz. (226.8 gm)

ELECTRICAL CHARACTERISTICS
DC Power
V_{CC} = +5V ±5%
I_{CC} = 1.5A max., 1.0A typical
V_{DD} = +12 ±5%
I_{DD} = .06A max., .04A typical
V_{BB} = −9V ±5%
I_{BB} = 0.10A max., 0.06A typical

ENVIRONMENTAL CHARACTERISTICS
Operating Temperature: 0° to +70°C

EQUIPMENT SUPPLIED
PC Assembly
Schematic Diagram
Assembly Drawing

OUTPUT MODULE

SPECIFICATIONS

WORD SIZE
8-bits

CAPACITY
Eight 8-bit latching output ports expandable in groups of 8 to 256 output ports.

INTERFACE CHARACTERISTICS
TTL compatible-output data complemented

CONNECTORS
Edge Connector: Dual 50-pin on 125 mil centers. Connectors in rack must be positioned on 500 mil centers minimum.
PN C800100 from SAE
PN VPB01C50E00A1 from CDC
Output Connector: 50 pin ribbon connector
PN3417 from 3M

PHYSICAL CHARACTERISTICS
Width: 0.062 in. (1.57 mm)
Height: 6.18 in. (157 mm)
Depth: 8.00 in. (203 mm)
Weight: 6.03 lb. (186.6 gm)

ELECTRICAL CHARACTERISTICS
DC Power:
V_{CC} = +5V ±5%
I_{CC} = 0.840A max, 0.420A typical

ENVIRONMENTAL CHARACTERISTICS
Operating Temperature:
0°C to 70°C

EQUIPMENT SUPPLIED
Printed Circuit Assembly
Cable Assembly
Schematic Diagram
Assembly Diagram

INPUT/OUTPUT MODULE

SPECIFICATIONS

WORD SIZE
8-bits

CAPACITY
Four 8-bit input ports, four 8-bit latching output ports expandable in groups of 8 to 256 input and 256 output ports.

INTERFACE CHARACTERISTICS
Input ports: TTL compatible-input data complemented
Output ports: TTL compatible-output data complemented

COMMUNICATIONS INTERFACE
Direct: TTL compatible input and output with crystal controlled transmission rates of 110, 1200 or 2400 baud.
TTY: 20mA TTY interface with discrete transmitter and receiver
TTY Reader Control: discrete relay interface

CONNECTORS
Edge Connector: Dual 50 pin on 125 mil centers. Connectors in rack must be positioned on 500 mil centers minimum.
PN C800100 from SAE.
PN VPB01C5E00A1 from CDC
Output Connector: 50 pin ribbon connector
PN3417 from 3M

PHYSICAL CHARACTERISTICS
Width: 0.062 in. (1.57 mm)
Height: 6.18 in. (157 mm)
Depth: 8.00 in. (203 mm)
Weight: 7 oz. (198.4 gm)

ELECTRICAL CHARACTERISTICS
DC Power:
V_{CC} = +5V ±5%
V_{DD} = −9V ±5%
V_{GG} = −12V ±5%
I_{CC} = 0.820A max., 0.478A typical
I_{DD} = 0.080A max., 0.050 typical
I_{GG} = 0.030A max., 0.016A typical

ENVIRONMENTAL CHARACTERISTICS
Operating Temperature: 0°C to 70°C

EQUIPMENT SUPPLIED
Printed Circuit Assembly
Cable Assembly
Schematic Diagram
Assembly Diagram

RAM MEMORY MODULE

SPECIFICATIONS

MEMORY SIZE
4K bytes

WORD SIZE
8 bits

MEMORY EXPANSION
To 65K bytes (16 modules)

CYCLE TIME
900 ns

INTERFACE
TTL compatible inputs; open collector outputs (positive true logic)

CAPACITY
4096 bytes*

CONNECTOR
Dual 50-pin on 125 MIL centers.
Connectors in rack must be positioned on 500 MIL centers minimum
Edge Connector:
P/N C800100 from SAE
P/N VPB01C50E00A1 from CDC

PHYSICAL CHARACTERISTICS
Width 0.062 in. (1.57 mm)
Height 6.18 in. (157 mm)
Depth 8.00 in. (203 mm)
Weight 8 oz. (226.8 gm)

ELECTRICAL CHARACTERISTICS
DC power:
V_{CC} = +5V ±5%,
I_{CC} = 2.5A max., 1.25A typical

ENVIRONMENTAL CHARACTERISTICS
Operating temperature: 0°C to 70°C

EQUIPMENT SUPPLIED
Printed Circuit Assembly
Schematic Diagram
Assembly Diagram

MICROCOMPUTER DEVELOPMENT SYSTEM

Complete hardware/software development system for the design and implementation of 8080 CPU-based micro-computer systems.

SPECIFICATIONS

WORD SIZE
Data: 8 bits
Instruction: 8, 16, or 24 bits

MEMORY SIZE
10k bytes expandable to 16k bytes within system chassis; 64k bytes in external user designed enclosures.

INSTRUCTION SET:
78, including conditional branching, binary arithmetic, logical, register-to-register and input/output memory reference with four addressing modes.

MACHINE CYCLE TIME
2.5 μs

SYSTEM CLOCK
Crystal controlled at 2 MHz ± 0.01%

I/O CHANNELS
Maximum Input/Output configuration available with I/O or Output Modules.

	Input Ports	Output Ports
imm8-61	16	16
imm8-63 (with one imm8-61)	4	28

INTERRUPT
Standard via control console. User designed multiple level interrupt capability available.

DIRECT MEMORY ACCESS
Standard via control console. User designed DMA capability available.

MEMORY ACCESS TIME
1 μs with standard memory modules. Faster access time available with user designed memory systems.

PHYSICAL CHARACTERISTICS
Intellec 8/MOD 80: 7" x 17⅛" x 12¼" (table top only)
Bare Bones 80: 6¾" x 17" x 21" (suitable for mounting in standard RETMA 7" x 19" panel space)
Weight: 30 lb. (13.61 kg)

ELECTRICAL CHARACTERISTICS
DC Power Supplies:
V_{CC} = 5V, I_{CC} = 12A*
V_{DD} = −9V, I_{DD} = 1.8A*
V_{GG} = +12V, I_{GG} = 0.06A

DC Power Requirement:
V_{CC} = 5V ±5%,
I_{CC} = 11A max., 6A typ.
V_{DD} = −9V ±5%,
I_{DD} = 1A max., 0.5A typ.
V_{CC} = +12V ±5%,
I_{GG} = 0.06A max., 0.04A typ.

AC Power Requirement:
50-60 Hz, 115/230 VAC, 200 Watts
*Larger power supplies may be required for expanded systems.

ENVIRONMENTAL CHARACTERISTICS
Operating Temperature: 0°C to 55°C

OPTIONAL MODULES
Available for the Intellec 8/MOD80 and Bare Bones 80:
imm8-61 I/O Module
imm8-63 Output Module
imm6-28 RAM Memory Module
imm6-70: Universal Prototype Module
imm6-72: Module Extender
imm6-36: Drawer Slides and Extenders for Rack Mounting

EQUIPMENT SUPPLIED:
Central Processor Module
Input/Output Module
PROM Memory Module
Two-RAM Memory Modules
PROM Programming Module
Chassis with Mother Board
Power Supplies
Designer's Console
Finished Cabinet
PROM Resident System Monitor
RAM Resident Macro-Assembler
RAM Resident Text Editor
Complete Hardware and Software Documentation including schematics and assembly drawings.

Figure A-2 presents the mini-processor configuration that was synthesized as a representative model. It is intended to be an integral part of the experiment subsystem, and nominally performs all computerized experiment services that are not accomplished by micro-processors. All assemblies are *stand-alone* and are available as commercial equipment, except for the BIA card discussed previously.

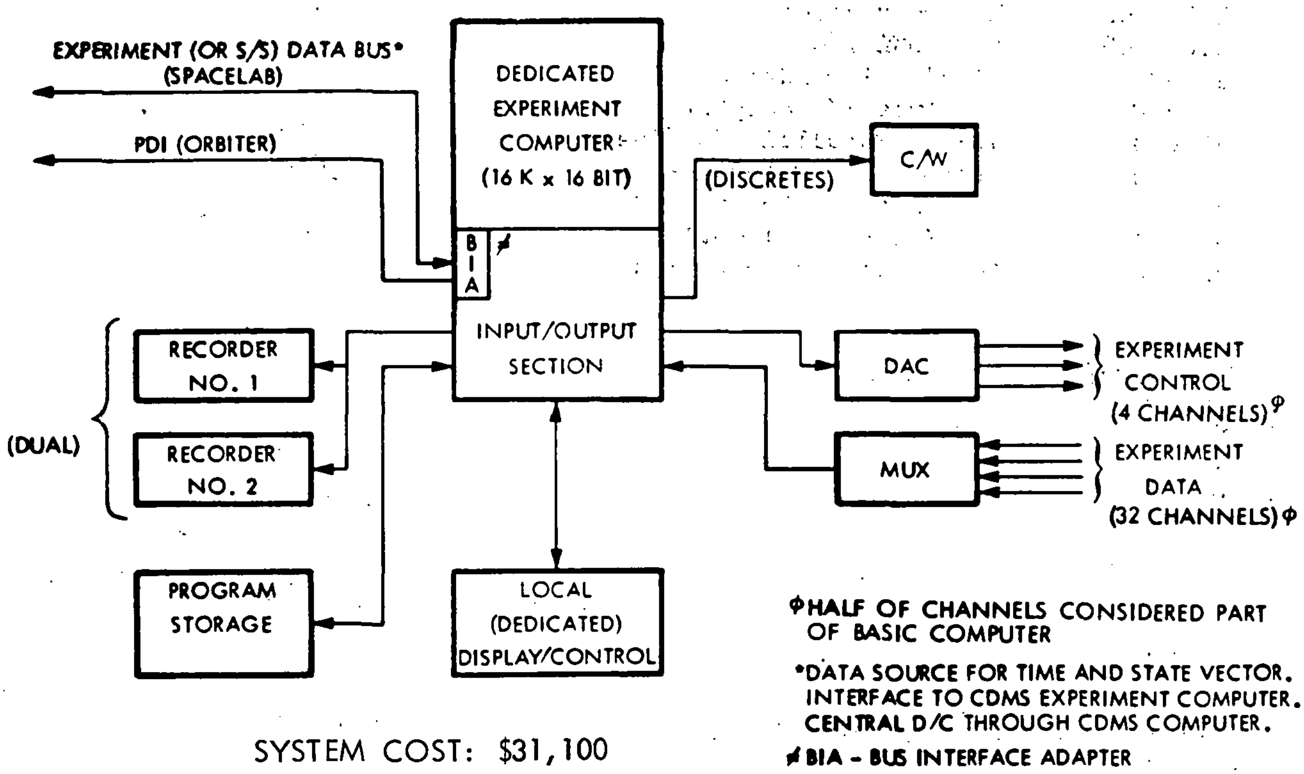


Figure A-2. Mini-Computer Flight Set

Programs are prepared for this machine using the FSSS and the machine configuration shown in Figure A-3. Note that this is the same machine as in the flight configuration with a hard-copy printer added. Thus, the flight set computer can be used to prepare the flight software. The cost of the elements that comprise the flight and test set configurations are itemized in Table A-2.

Figure A-4 represents the mini-computer ground set. This would be used by the mission support personnel to run (not develop) the ground support application programs using the ground software support system (GSSS). Note that the majority of the equipment is the same as that used in the flight mini-processors. The only unique ground processing equipment is the memory disc set ($16K).

Equipment descriptor sheets for the major components of the mini-processor system are included.

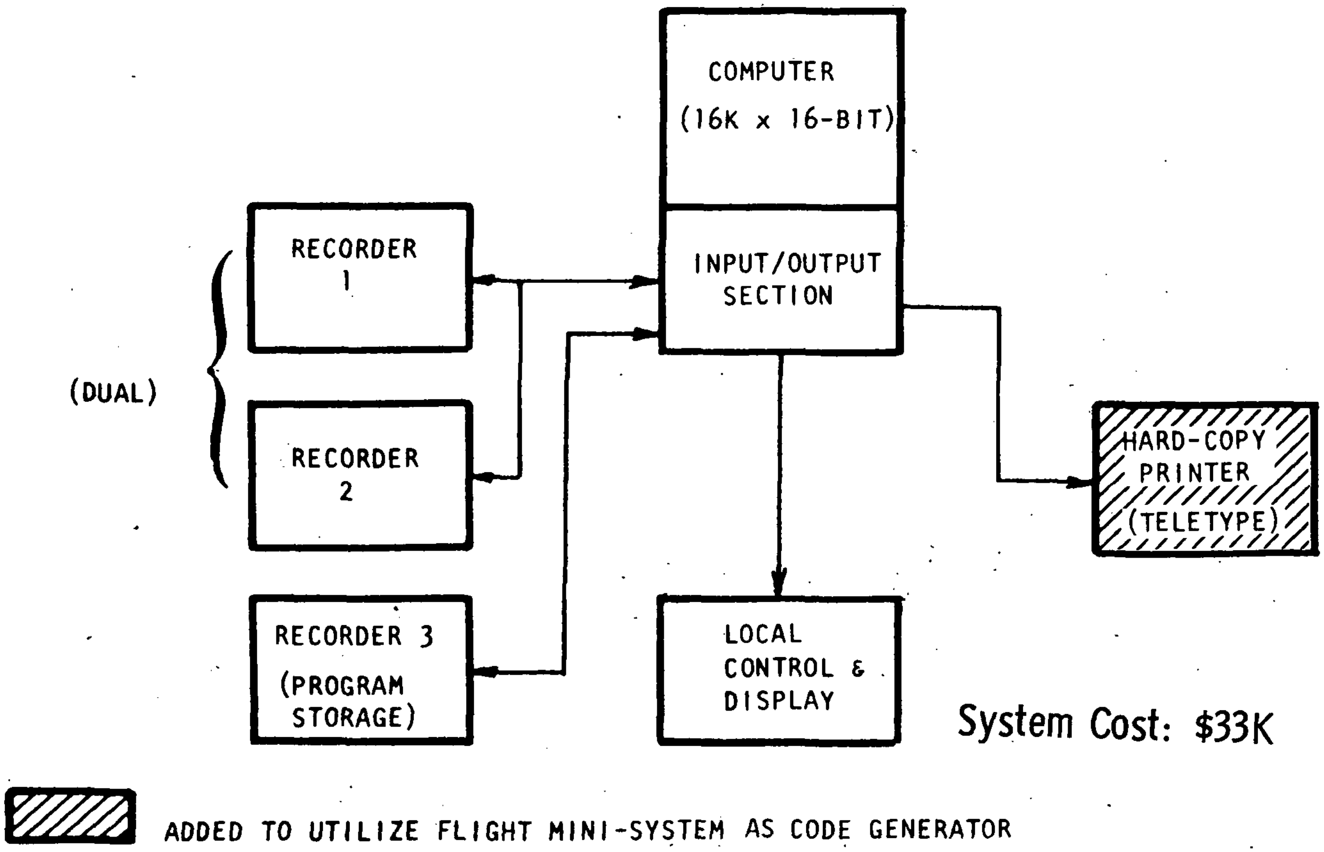


Figure A-3. Mini-Computer-Based Flight Code Generator Model
(Software Development Test Set)

Space Division
Rockwell International

Table A-2. Mini-Computer System Complement

Basic Computer

HP 2112A	Main Frame	$ 6,200
2102A	Memory Controller	500
2102A-008	8K x 16-bit Memory Module (2 req'd)	3,000
2102A-003	Memory Protect	500
2102A-001	Dual DMA I/O	750
12880A	Display I/O Adapter	570
12531C	Teletype I/O Adapter	570
12566B	16-bit Parallel I/O (Dual)	500
Custom	Reacorder I/O Adapter	1,600
12555B	DAC (2 ch. x 8-bit)	600
91000A	ADC (15 ch. x 12-bit)	2,000
12944A	Power Fail Recovery System	475
		$17,265

Added Computer I/O Modules

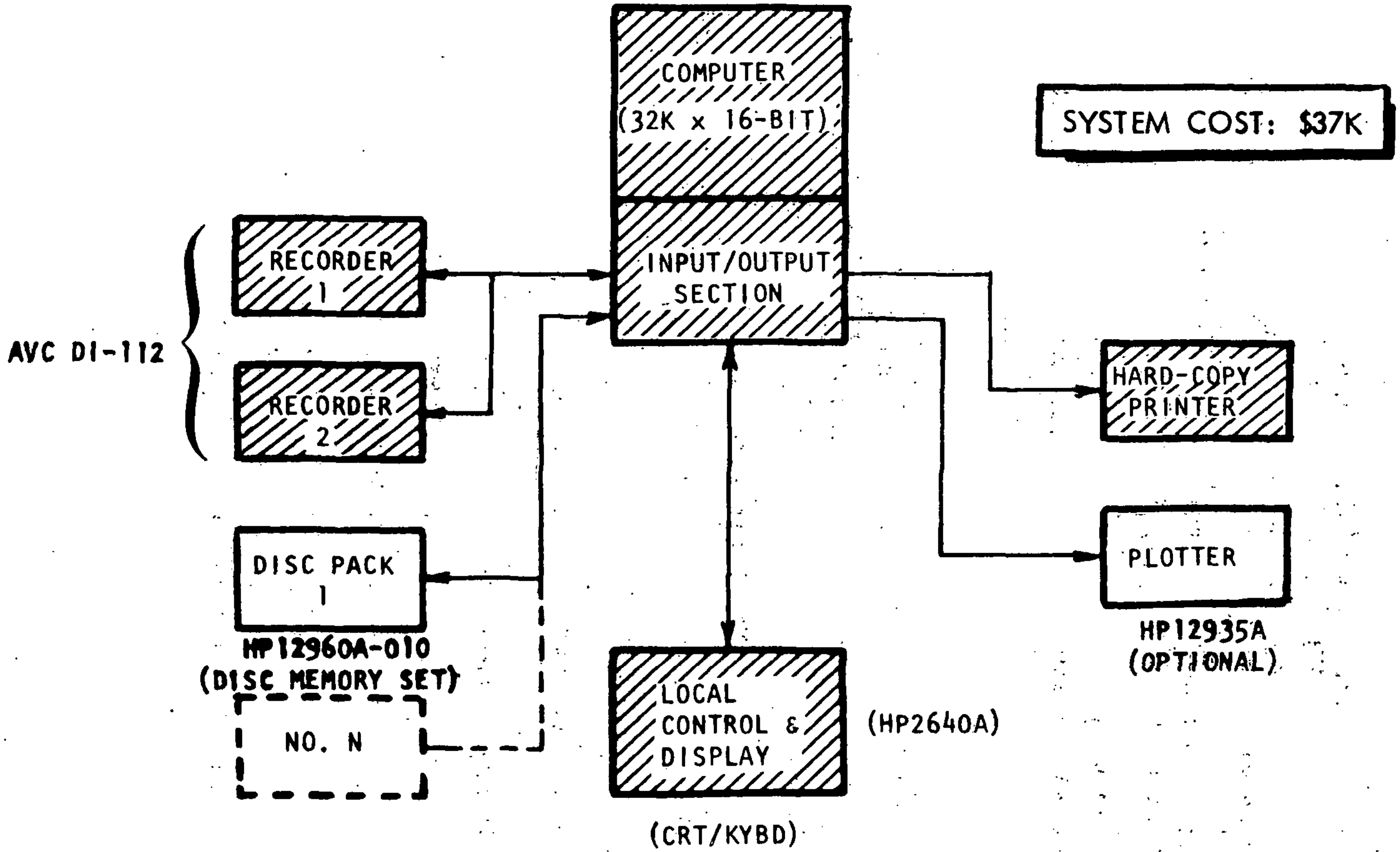
Custom	Bus Interface Adapter	$ 3,000	
HP 12555B	DAC	600	
HP 91000A	ADC	2,000	
		$ 5,600	
	Total Processor Costs		$22,865

Peripherals

HP 2640A	CRT/Keyboard Terminal	$ 3,000	
AVC D1-112 (Dual)	Dual Tape Recorder (Cassette)	3,400	
AVC D1-112 (Single)	Single Tape Recorder (Cassette)	1,835	
		$ 8,235	
	Total System Costs		$31,100

Test Set Peripheral

HP 2752A	Teletype Terminal (Hardcopy Printer)	$ 2,000



COULD BE SAME EQUIPMENT USED IN FLIGHT PROCESSOR

GROUND PROCESSING UNIQUE EQUIPMENT

Figure A-4. Ground Processing Model

Space Division
Rockwell International

-PRELIMINARY-

HP 21MX Computer Series Microprogrammable Processors

The Hewlett-Packard 21MX is a family of new microprogrammable processors utilizing the latest in semiconductor technology. Standard features on all members of the family include a powerful instruction set with floating point and data communication instructions, integer arithmetic, automatic parity generation and checking, and fully independent memory and I/O sections in the computer mainframe. Plug-in instructions are available to increase the performance capability of the 21MX.

The power and speed of microprogramming is readily available to the user in the form of Writable Control Store modules or may be permanently fused into Programmable Read-Only Memory (PROM) and plugged into the control store section of the processor.

A comprehensive range of standard software is available for the M/10, M/20, and the M/30 processors including assemblers, compilers, and operating systems. In addition, a full line of HP manufactured peripherals and data communications interface kits are available, enabling complete systems to be tailored around this new family of microprogrammable processors.

Product Specifications

CONTROL STORE
Type: Bipolar LSI ROM Semiconductor
Size: Up to 3 ROM control store boards plus WCS

CONTROL PROCESSOR
Address Space: 4096 words – 16 modules of 256 words each
Word Size: 24 bits
Word Formats: 4
Word Fields: 5
ROM Cycle: 325 nanoseconds

Micro orders: 178 total
Operations: 15 total
Special: 32 total
ALU and Conditional: 67 total
Store: 32 total
S Bus: 32 total

Module Assignments:
0, 14, and 15 assigned to MX Base Instruction Set;
module 1 is used for front panel control;
module 2 is used for DMS instructions;
modules 3, 4, and 5 are used for the Fast Fortran Processor
modules 6-11 are for planned HP enhancements or user microprogramming
modules 12 and 13 are reserved for user enhancements

PROCESSOR REGISTERS
Standard Registers
Accumulators: two (A and B), 16 bits each. Implicitly addressable, also explicitly addressable as memory locations
Index: two (X and Y) 16 bits each
Memory Control: three (T,P), 16 bits each, (M), 15 bits
Supplementary: two (overflow and extend), one bit each
Manual Data: one 16 bit (display)

Control Processor Registers
Scratch Registers: 12 16-bit registers accessible to the microprogrammer
Iteration Counter: 8 bits
Latch Register: 16 bits
Status Flag: 1 bit

INSTRUCTION EXECUTION TIMES
(Using Main Memory System)

	Min. μsec.	Max. μsec.
Memory Reference Group (14 total)	1.9	2.9
Register Reference Group (43 total)	2.6	2.9
Input/Output Group (13 total)	2.6	3.9

Extended Arithmetic Instructions (10 total)

Multiply	12.3	13.0
Divide	13.6	17.5
Double Load		4.9
Double Store		4.9
Shift/Rotate	3.6	8.4
Indirect Addressing		1.3

Index Instructions 9 (X and Y registers) (32 total)

	Max. μsec.
Copy A/B to X/Y	2.3
Copy X/Y to A/B	2.3
Exchange Registers A/B - X/Y	3.3
Increment/Decrement Index Registers	3.3
Load Index	*4.9
Store Index	*5.2
Load A/B Registers, indexed	*4.9
Store A/B Registers, indexed	*5.2
Add Memory to Index Registers	*4.9
Jump and Load Y	*5.5
Jump and Index Y	4.6

*Plus 1.3 μsec. per level of indirect addressing

Data Communications Instructions (10 total)

	Setup μsec.	Execute μsec.
Load Byte	4.6	5.2/byte
Store Byte	5.8	6.2/byte
Move Bytes	8.8	7.3/byte
Move Words	7.8	3.3/word
Compare Bytes	8.8	8.1/byte
Compare Words	7.8	3.6/word
Scan for Byte	2.3	4.9/byte
Set Bits	7.8	
Clear Bits	7.8	
Test Bits	7.1	

Note: Multiple execute steps may take place for each instruction set up

Floating Point Firmware Instructions (6 total)

	Minimum	Maximum
Add	18.2 μsec.	73.4 μsec.
Subtract	19.2 μsec.	75.7 μsec.
Multiply	50.7 μsec.	57.5 μsec.
Divide	62.4 μsec.	84.2 μsec.
Fix	6.5 μsec.	13.0 μsec.
Float	11.7 μsec.	38.7 μsec.

MEMORY PARITY CHECK HALT ON ERROR
Operation: monitor all words read from memory · Utilizes 17th bit in memory. Switch programmable to halt or ignore parity error when detected. Interrupt on error requires X/Series Memory Protect Option. A parity error indication is displayed on the front panel

POWER FAIL INTERRUPT
Priority: highest priority interrupt
Power Failure: detects power failure and generates an interrupt to trap cell for user-written power failure routine, terminates activities, and halts the processor. 500 microseconds minimum are available for the routine. Power fail recovery is available as an X/Series memory system option

LOADER PROTECTION
All loaders reside in special ROM's separate from the control ROM and are loaded into the last 64 words of main memory by activating front panel switches. Paper tape loader is standard and a disc loader ROM is optional. A total of four switch selectable loader spaces are provided to accommodate other modes of operation as a user option. User generated loaders may be written in Assembly Language and burned into PROMS.

VOLATILITY PROTECTION
AC standby mode and sustaining power for line loss of 40 milliseconds before entering Power Fail Routine. Power Fail Recovery system is an X/Series memory system option.

INPUT/OUTPUT
Multilevel Vectored Priority Interrupt: determined by interface location

I/O SYSTEM SIZE

	M/10	M/20	M/30
I/O channels standard	4	9	14
with one extender	20	25	30
with two extenders	36	41	46

I/O Compatibility: hardware and software compatible with all HP 2100 Series computers (time loop dependent programs excepted), as well as total family compatibility

Current Available to I/O: assume 32K mainframe memory, Dual-Channel Port Controller, maximum available CPU mounted control store, and memory protect in M/20 and M/30

	Total Current (Amperes)		
Supply (VDC)	M/10	M/20	M/30
+5	6.0	13.0	28.0
-2	2.0	4.0	8.0
+12	1.0	2.0	3.0
-12	1.0	2.0	3.0

PHYSICAL CHARACTERISTICS
Width: 16-3/4 inches (42.55 cm) behind rack mount, 19 inches (48.26 cm) front panel width on sides
Depth: 23-1/2 inches (59.69 cm) 23 inches (58.42 cm) behind rack mounting ears

	M/10	M/20	M/30
Height:	5-1/4 in. (13.31 cm)	8-3/4 in (22.23 cm)	12-1/2 in. (31.69 cm)
Weight:	39 pounds (17.69 Kg)	45 pounds (20.41 Kg)	65 pounds (29.48 Kg)

ELECTRICAL
Line Voltage: 110/220 VAC ±20%
Line Frequency: 47.5 to 66 Hz

	M/10	M/20	M/30
Power (max.)	400W	525W	800W

Power Supply
Storage After Line Failure: sustains processor over a line loss of 2.5 cycles when operating at the normal 110/220 VAC
Input Line Over Voltage Protection: input crowbar is in series with line fuse for line voltages >40% above nominal
Output Protection: all voltages are protected for overvoltage and over current
Output Voltage Regulation: ±5%
Thermal Sensing: monitors internal temperature and automatically shuts down if temperature exceeds specified level

ENVIRONMENT
Operating Temperature: CPU 0° to 55°C(+32° to 131°F)
Storage Temperature: -40° to 75°C(-40° to 167°F)
Relative Humidity: 20% to 95% at 40°C(104°F), no condensation
Ventilation:
Intake: Left hand side
Exhaust: Right hand side

	M/10	M/20	M/30
Heat Dissipation: (BTU/hr. maximum)	1365	1795	2730

Altitude: transportable to 40,000 feet in non-operating condition and 15,000 feet for operation

Vibration and Shock: type tested to qualify for normal shipping and handling shock and vibration
Vibration: .012 inches (.30 mm) p-p, 10-55 Hz, 3 axis
Shock: 30g, 11 Ms, 1/2 sine, 3 axis

Contact factory for review of any application regarding operation under continuous vibration

WRITABLE CONTROL STORE
Capacity:
Words Available: 256 per module

	M/10	M/20	M/30
Maximum WCS Modules	1	2	3

Word Size: 24 bits
Maximum instruction entries: 32 per module
Microinstruction Time: 325 nanoseconds
Programming: uses Input/Output Group Instructions or an X-Series Dual-Channel Port Controller (if present) to load the internal RAM
Dimensions:
Width: 7-3/4 inches (196 millimeters)
Height: 8-11/16 inches (222 millimeters)
Current Required:
+5.0 volts supply 4.6 amperes
-2.0 volts supply 0.15 ampere

I/O EXPANSION
I/O Extender, provides power supply and prewired slots for 16 additional I/O channels. Two extenders may be connected together to produce 32 additional I/O channels. Each extender occupies an I/O slot in the CPU
Optional:
Dual-Channel Port Controller Extender
Second Extender Unit
230 VAC/50 Hz operation

DYNAMIC MAPPING SYSTEM
DMS gives the user an addressing space of one million words, provides page by page memory protection, and provides four separate dynamically alterable memory maps, containing a total of 128 registers, to allow programs and data to be loaded and executed from non-contiguous pages of memory. All systems using DMS execute with the same memory cycle time as the regular systems. Instructions Occupy Control Store Module 2.

FAST FORTRAN PROCESSOR
FFP consists of 24 microcoded instructions which greatly enhance the througput efficiency of programs requiring multidimensional arrays, double precision variables, subroutine calls, etc.
Occupies Control Store Modules 3, 4, and 5.

Product Support

SOFTWARE SUPPLIED

Diagnostics	24390-16001
	24390-16002
	24390-16003

DOCUMENTATION SUPPLIED

Long Diagnostic Reference Manual	24390-90001
21MX Computer Series Reference Manual	02108-90002
Microprogramming manual	02108-90008
Operators manual	02108-90004
Installation and Service manual	02108-90006

ORDERING INFORMATION

Specify	Description
2105A	M/10 Processor*
2108A	M/20 Processor*
2112A	M/30 Processor*

*For Memory Systems see X/Series Data Sheet.

PROCESSOR OPTIONS

21xx -015 230V/50 Hz Operation

ACCESSORIES AND FIELD UPGRADES

Specify		Description
12892A		Memory Protect
12897A		Dual-Channel Port Controller
12976A		Dynamic Mapping System
12977A		Fast FORTRAN Processor
12978A		Writable Control Store
12909B		PROM Writer
12945A		User ROM Control Store Board
12990A		Memory Extender
12991A		Power Fail Recovery for Memory Extender
12992A		Disc Loader ROM
12979A		I/O Extender
	-010	Second Extender
	-015	230V/50 Hz operation.

HP 2644A Mini Data Station

ENHANCED HIGH RESOLUTION DISPLAY

The 2644A displays 1,920 characters in a 24 line by 80 column format on a 5 inch by 10 inch display. A 9 X 15 dot character cell allows large characters to be represented accurately. Dot shifting for smooth characters, wide character and line separation, inverse video, and optional plug-in character sets with underlining, half-bright, and blinking are features engineered to increase clarity and ease sessions at the terminal.

CHARACTER/BLOCK MODE WITH EDITING, FORMS MODE

The 2644A transmits character-by-character as an interactive terminal and is capable of operating on a block at a time. Local editing allows the terminal user to verify and correct data before transmission to the CPU. Standard features include character or line insert and delete, cursor sensing and positioning, programmable protected fields for forms, off-screen storage with scrolling and page select, tabulation, displayable control codes, 8 function keys for user defined routines, and a positional memory lock. Optional math and line drawing character sets enhance display presentations.

MODULAR ARCHITECTURE, MICROPROCESSOR CONTROLLED

Microprocessor implementation and single bus architecture produce a terminal with a wide range of capabilities. Engineered for high reliability and ease of service, the 2644A's TEST button gives the user a GO/NO-GO verification of proper operation.

Cartridge Tape: Two mechanisms
- Read/Write speed: 10 ips
- Search/rewind speed: 60 ips
- Recording: 800 bpi

Mini Cartridge: 110 kilobyte capacity (maximum per cartridge)

DATA COMMUNICATIONS

Data Rate:
- ASCII Mode: 110, 150, 300, 1200, 2400 baud, and external–switch selectable (110 selects two stop bits)

Communications Interface: EIA standard RS232C; 103 and 202 modem compatible
Transmission Modes: Full or half duplex, asynchronous
Operating Modes: On-line; Off-line; Character, Block
Parity: Switch selectable; Even, Odd, None

ENVIRONMENTAL CONDITIONS

Temperature, Free Space Ambient:
- Non-Operating: –10 to +65°C (–15 to +150°F)
- Operating: 5 to +40°C (+41 to +104°F)

Humidity: 20 to 80% (non-condensing)
Heat Dissipation: 483 BTU/hour

System Specifications

GENERAL

Screen Size: 5 inches (127 mm) X 10 inches (254 mm)
Screen Capacity: 24 lines X 80 columns (1,920 characters)
Character Generation: 7 X 9 enhanced dot matrix; 9 X 15 dot character cell; non-interlaced raster scan
Character Size: .097 inches (2.46 mm) X .125 inches (3.175 mm)
Character Set: 64 upper-case Roman
Cursor: Blinking-Underline
Display Modes: White on Black; Black on White (Inverse Video)
Refresh Rate: 60 Hz (50 Hz optional)
Tube Phosphor: P4
Implosion Protection: Bonded implosion panel
Memory: MOS; ROM; 12K bytes (program); RAM: 4096 bytes
Keyboard: Full ASCII Code Keyboard, 8 special function keys, and 16 additional control and editing keys; Ten-key numeric pad; Cursor pad; Multi speed auto-repeat; N-key roll-over; Stand-alone, 4 foot cable.

Product Support

HARDWARE SUPPLIED

2644A Mini Data Station
9162-0061 Data Cartridge (Three)

DOCUMENTATION SUPPLIED

Model 2644A Mini Data Station Owner's Manual (02644-90011)
Installation and Service Manual (02644-90012)

12970A DIGITAL MAGNETIC TAPE SUBSYSTEM (NRZI)

System Specifications

TRANSPORT

Number of tracks - nine
Density: 9-track: 800 cpi
Write Enable - supply reel ring required to write
Reel Diameter - up to 10.5 inches (266.7 mm)
Read/Write Speed - 25, 37.5, or 45 ips
Data Transfer Rate - 36 kHz (800 cpi, 45 ips)
Rewind Speed - 160 ips

Tape

Width - 0.5 inches (12.7 mm)
Thickness - 1.5 mils (0.038 mm)
Start/Stop Times - 8.33 ms (read/write) at 45 ips
End-of-Tape/Beginning-of-Tape Detection - IBM compatible

Controls

RESET - stops tape travel in any mode and returns unit to local control
REWIND - initiates rewind
ON-LINE - places unit under remote control
LOAD - tensions unit and initiates load point search

Indicators

WRITE ENABLE - Illuminated when write enable ring is installed on the supply reel
LOAD POINT - Illuminated when the Beginning of Tape (BOT) strip is detected

Cable

Length (Controller to transport): 15 feet (457 cm)

Controller

Commands:
- Select Unit - 1 of 4
- Write Record
- Write File Mark
- Gap and Write File Mark
- Gap
- Read Record
- Forward Space Record
- Backspace Record
- Forward Space File
- Backspace File
- Rewind
- Rewind/Off-line

Status:
- Off-line
- Data/Timing Error
- File Protected
- Command Rejected
- End-of-Tape
- Load Point
- Busy
- Rewind In-Process
- Odd Byte
- Selected Tape Unit

Physical Characteristics

Height: 24 in. (60.9 cm)
Width: 19 in. (48.2 cm)
Depth: 12 in. (30.4 cm) from mounting surface
Overall Depth: 15-3/4 in. (40.0 cm)
Weight: 130 lbs. (59,02 Kg) maximum

Mounting:

Standard 19 inch (482,6 mm) RETMA rack. Hardware supplied for mounting in standard HP rack.

Environmental (Hardware)

Ambient Temperature - 32° to 131°F (0° to 55°C)
Relative Humidity - 20% to 80% (non-condensing)

Power

7970B: 115 or 230 VAC ±10% (switch selectable)
48 to 60 Hz single phase
400 VA maximum (high line)
Interface: 2.9A (+4.5V); 0.09A (-2V)

Product Support

Hardware Supplied 12970A:
7970B - 9-track, 800 CPI, Read-after-write

13181A - interface controller (uses two I/O slots and operates up to four drives of the same type and speed) and interconnecting cables

12892A MEMORY PROTECT OPTION

The Memory Protect Option 12892A interfaces with the CPU similar to an I/O device and is located in the memory section. It provides an operating system with the ability to protect itself from alteration , and preserves system control of I/O functions. It also provides software with the capability to detect the location of parity errors by generating a parity interrupt, and to prevent indirect addressing from holding off interrupt servicing.

Product Specifications

PHYSICAL CHARACTERISTICS
Weight: 0.61 pounds (270 g)
Size: 7-3/4 x 8-3/8 inches (18.7 x 21.3 cm)
Standard HP 21MX I/O board size

ELECTRICAL
Same as HP 21MX processor specifications

POWER REQUIRED
+5V -2a
-2V +0.05a

ENVIRONMENT
Class B (same as HP 21MX)

Product Support

HARDWARE SUPPLIED
HP 12892-60001 Memory Protect Card

SOFTWARE SUPPLIED
21MX Series Memory Protect Diagnostic -- 24324-16001
21MX Series Memory Parity Check Diagnostic – 24325-16001

DOCUMENTATION SUPPLIED
Installation manual -- 12892-90001
21MX Series Memory Protect Diagnostic Manual – 02100-90220
21MX Series Memory Parity Check Diagnostic Manual – 02100-90221

INSTALLATION
Insert the 12892A board directly into slot 111 of memory backplane. No cables required.

ORDERING INFORMATION
Order: HP 12892A Memory Protect for 21MX Computers

Note: Memory Protect is not available for the M/10 Processor (2105A).

12566B MICROCIRCUIT INTERFACE

The Microcircuit Interface card permits interfacing to an external device with the popular DTL/TTL family of integrated circuits, at data speeds much greater than can be achieved with discrete-components. Typical devices are those used for on-line production testing, lab design work, and those applications involving measuring instrumentation. The interface card permits input and output information flow between the computer and an external device. It features separate 16-bit input and output storage registers, plus control and interrupt logic. These features offer a wide latitude in configuring your instrument measurements for computer analysis.

Product Specifications

PHYSICAL CHARACTERISTICS
Width: 196.8 mm (7-3/4 inches)
Height: 220.7 mm (8-11/16 inches)
Net weight: 511.2 gm (1.12 lb)
Shipping weight: 2.27 kg (5 lb)

ENVIRONMENT
The 12566B meets all HP 2100 and 21MX Series Computer environmental specifications.

Product Support

SOFTWARE SUPPLIED
Diagnostic Program

DOCUMENTATION SUPPLIED
Operating and Service Manual

INSTALLATION
Installs in any 2100 and 21MX Series Computer I/O slot.

HARDWARE SUPPLIED
HP 12566B Interface Kit, consisting of:
- Microcircuit Interface card, Part No. 12566-60024 (Ground true, Positive-false)
- Connector Kit, 48 pin (for interconnect cable), Part No. 5060-8317
- Cable, 36 twisted-pair leadwires, 15 feet long, Part No. 8120-1445
- Connector, 24 pin, Part No. 1251-0332 (for test purposes only)

HP 21MX COMPUTER SERIES
X/2 MOS RAM Memory System

The Hewlett Packard X/2 Memory System is a medium density main memory system for the HP21-M/Series processors,which utilize the latest in 4K. N-channel MOS/RAM chip semiconductor technology. User specified options include 4K and 8K word Memory Modules, Memory Protect with Parity Interrupt, Dual-channel Port Controller and Power Fail Recovery System.

Product Specifications

MEMORY ORGANIZATION

Type: 4K chip N-channel MOS/RAM semiconductor
Word Size: 16 bit with 17th parity bit
Configuration: Controller and multiple plug-in memory modules
Page Size: 1024 words
Direct Addressing: 2 pages
Indirect Addressing: 32K
System Cycle Time: 650 nanoseconds
Volatility Protection: AC standby mode and memory sustaining power for line loss of 10 line cycles is standard in the M/Series processor. The Power Fail Recovery System is optional
Power Fail Recovery System: Sustains memory integrity in case of total line failure for two hours in a 32K configuration

MEMORY SYSTEM

Basic system consists of controller and interconnecting cable for a full complement of memory modules. The system plugs into memory section card cage of the M/Series processors–memory size is configured by using multiples of 4K and 8K modules as defined in the price list configurator.

Memory Modules
Word Length: 16 bit with 17th parity bit
Module Configuration:
4K Word–MOS/RAM Semiconductor Main Memory Module
8K Word–MOS/RAM Semiconductor Main Memory Module

MEMORY PROTECT* (HP 21 - M/20 ONLY)

Priority: Second highest priority interrupt (shared with Memory Parity)
Operation: Initiated under program control; protects any amount of memory, I/O and Privileged Instructions when implemented in the HP 21 - M/20 Processor
Fence Register: Set under program control; memory below fence is protected.
Interrupt: To trap cell for system routine when user program
a) attempts to alter a protected location
b) attempts to jump into the protected area
c) attempts to execute an I/O instruction

Violation Register: Contains memory address of violating instruction.
Parity Error Interrupt: Provides interrupt signal when partiy error is detected save address of error in violation register.
Infinite Indirect Protection: Interrupts are enabled after 3 levels of indirect operation.

DUAL-CHANNEL PORT CONTROLLER*

Number of Channels: 2
Number of Memory Ports: 1
Registers per Channel: Word Count Register, Address Register
Word Size: 16-bits
Maximum Block Size: 32,768 words
Assignable: To any two I/O channels
Transfer Rate: 616,666 words per second maximum
Priority: Highest – DCPC Channel 1
Middle – DCPC Channel 2
Lowest – Processor
All logic necessary to facilitate bi-directional direct memory to I/O transfers is contained on this controller.

POWER FAIL RECOVERY SYSTEM

Power Restart: Detects resumption of power and generates an interrupt to trap cell for user written restart program which has been protected in memory by the sustaining battery
Power Control and Charge Unit: Monitors battery charge status, and provides slow charge

Sustaining Battery:
Type: 12 Volt Nickel Cadmium
Charging Rate: 350 milliamperes
Capacity: 4 ampere-hours; will sustain 32K words of main memory for a 2 hour period

PHYSICAL CHARACTERISTICS

Memory Controller, modules, Protect and Dual-channel Port Controller, all plug into assigned slots in the processor
Width: 7-3/4 inches (19.6 cm)
Height: 8-11/16 inches (22.2 cm)

ELECTRICAL

The M/Series processors provide the necessary D.C. power to accommodate all X/2 Series options

ENVIRONMENT (when installed in M/Series processor)

Operating Temperature: 0° to 55°C (+32° to +131°F)
Relative Humidity: to 95% at 40°C (104°F)
Ventilation (supplied by the processor)
Intake: Left hand side
Exhaust: Right hand side
Heat Dissipation: Largest memory configuration is 100 BTU/hr. maximum
Altitude: Transportable to 25,000 feet in non-operating condition and 15,000 feet for operation
Shock: The HP Quality Audit tests for 30g's of shock for 11 milliseconds over a 1/2 sinewave shape
Vibration: When mounted in the M/Series processor can withstand vibration of 1g at 44 Hz

*Plugs into the Memory Card Cage section of M/Series processors.

HP 21MX Computer Series 12978A Writable Control Store

Writable Control Store (WCS) Card contains semiconductor random-access memory for storage of microprograms. Each card contains 256, 24-bit words of storage. Up to two cards can be inserted in the computer mainframe.

Product Specifications

PHYSICAL CHARACTERISTICS
Width: 7-3/4 inches (19.6 cm)
Height: 8-11/16 inches (22.2 cm)

ENVIRONMENT
The 12978A meets all HP 21MX Computer environmental specifications.

ELECTRICAL
+5.0 volts supply 4.6 amperes
-2.0 volts supply 0.15 amperes

Product Support

HARDWARE SUPPLIED
HP 12978A Writable Control Store PCA (12908-60006)
Jumper Cable Assembly (5060-8393)

SOFTWARE SUPPLIED
Microprogram assembler, drivers, I/O utility program and Debug Editors for either HP Basic Control System or HP Disc Operating System and diagnostics
Microprograms callable from HP Assembly Language, FORTRAN II and IV, ALGOL, and HP Extended BASIC

DOCUMENTATION SUPPLIED
Microprogramming HP 21MX Computers, Reference Manual, (2108-90008)

INSTALLATION
Insert WCS in an I/O slot and connect the jumper cable assembly

2762A Terminal Printer

The HP 2762A is a medium speed computer terminal for direct or remote communication. It serves as a system console or terminal for HP computer systems.

Product Specifications

SYSTEMS COMPATIBILITY

2000 Series Timeshare Systems
2100 A/S or 21MX DOS Based Systems

CONTROL UNIT

Transmission: Full duplex, serial asynchronous; 7-level ASCII code plus parity (even), start and stop bits.

Interface: EIA Standard RS-232C (CCITT V-24). Compatible with Bell 103 series full duplex modems or equivalent. May be direct wired to HP 2100/21MX series computers via 12531D-001 Interface Kit or HP series 12920 Multiplexer.

PRINTING SYSTEM

Revolving print font belt: ink ribbon
Ink standard color: black
Printable characters: 94
Print positions (line length): 75 (characters)
Horizontal spacing: 10 characters per inch (2.54 cm)
Vertical spacing: 6 or 3 lines per inch (determined by Line Space switch)
Printed character size (typical)
Height: 2.5 mm (0.1 inch) nominal
Width: 1.5 to 2.2 mm (0.060 to 0.085 inch)

Forms: (Pin feed equipped units) One to six-part carbon forms or three-part carbonless, sprocketed forms 21.6 cm (8.5 inches) wide, 20.3 cm (8.0 inches) between feed holes.

Recommended paper weights:

1 part	15 lb. paper
2, 3, 4 parts	13.5 lb. paper, 8 lb. carbon
6 part	12 lb. paper, 8 lb. carbon

Maximum allowable pack thickness: 0.64 mm (0.025 in.)
Paper slew rate: 16.9 cm (6.66 in.) per second
Indicators: local, standby, on-line, ready, interrupt, alarm, print position

KEYBOARD

Magnetically coupled key contacts ensure reduced wear, longer operating life, and high reliability. The full 128-character ASCII codes (94 printable) can be generated.

Switches: All Caps, Auto Line Feed

PRINTING SPEED

10, 15, or 30 characters/second, switch selected.

DATA TRANSFER

Bit serial 10-bit code (11-bit at 10 cps) at rates of 110, 150, or 300 baud.

NUMBER OF COLUMNS

75 columns

CODE CONFORMATION

The 2762A Terminal Printer conforms to the following codes and standards:
Underwriters' Laboratory Standard 478 (60 Hz only)
Canadian Standards Association (60 Hz only)
Federal Communications Commission Rule 15
Electronic Industries Association Standard RS-232C
American National Standard USAS X3.4-1968
International Electrotechnical Commission 335-1 (50 Hz only)

ENVIRONMENT

Operating Temperature: 0° to 43°C (+32° to 110°F)
Storage: -28° to +71°C (-20° to +160°F)
Humidity, Operating and Non-Operating: 10 to 95% (non-condensing)
Altitude:
Operating: 0 to 3,650 m (12,000 ft.)
Non-Operating: 0 to 15,240 m (50,000 ft.)

POWER REQUIREMENTS

2762A Terminal

60 Hz models:	117 VAC ±10% Single Phase 60 Hz -1.5 to +1 Hz Line Frequency
50 Hz models:	220 or 240 VAC (dependent on option) ±8% 50 Hz ±0.5 Hz
Power Consumed:	110 watts maximum
Power Cable:	3-wire, 7 ft. (2.1 m)

PHYSICAL CHARACTERISTICS

Width: 52 cm (20-3/8 inches)
Height: 19 cm (7-1/2 inches)
Depth: 67.3 cm (26-1/2 inches)
Weight: 36.3 kg (80 pounds) without pedestal
45.5 kg (100 pounds) including pedestal
Shipping Weight: 59.1 kg (130 pounds) without pedestal
75 kg (165 pounds) with pedestal

EQUIPMENT SUPPLIED

The following is shipped with each 2762A:
Data Set Cable, RS-232C (CCITT V-24) Compatible, Length: 1.4 m (4.5 ft.)
Dust Cover
Spare Lamps and Lamp Extractor
Power Cord
9280-0292 Paper, 1 roll (friction feed models only)*
9280-0705 Paper, fan fold, 250 sheets (pin feed models only)*
9282-0524 Ribbon, black
02762-90030 Operators Manual

MINI-COMPUTER TELEPRINTER

EQUIPMENT SUPPLIED

HP 2752A or HP 2754B Teleprinter, includes stand and 16-foot interconnecting cable plus the following:

With each 2752A: one roll paper, 8-1/2 inches wide, 370 feet per roll, HP Part No. 9280-0046, power pack, chad box, copy holder, paper shaft and paper tape spools.

With each 2754B: one box of fanfold paper, 3500 8-1/2 by 11 sheets, Part No. 9280-0705.

One roll paper tape, 1-inch wide, 1000 feet per roll, HP Part No. 9280-0063.

Lubrication Kit, HP Part No. 5080-6610.

HP 12531C Interface Kit consisting of:

Buffered Teleprinter Interface Card, HP Part No. 12531-60022.

BCS Buffered Teleprinter Driver Tape, Accessory No. 20017C.

SIO Buffered Teleprinter Driver Tape, Accessory No. 20322A (4K Memory) or Accessory No. 20323A (8K Memory), or Accessory No. 20330B (16K Memory).

Buffered Teleprinter Test — Binary Tape, Accessory No. 20417C (2116), 20420B (2114 and 2115), or 24201A (2100).

SPECIFICATIONS

(The following applies to both HP 2752A and HP 2754B Teleprinters, except as noted.)

TAPE PUNCHING AND READING SPEED

10 characters per second

TYPING SPEED

100 words per minute (maximum)

TAPE CODE

8-channel on 1-inch paper tape

DATA TRANSFER

Bit serial; 8-bit code

PLATEN

2752A: Friction-feed
2754B: Pin-feed

POWER REQUIRED

HP 2752A: 115V, 60 ± 0.45 Hz or 50 ± 0.45 Hz, 230W
HP 2754B: 115V, 60 ± 0.5 Hz, 230W (Consult factory if 50 Hz operation is desired)

(HP 2752A Teleprinter is available with 230V, 50 Hz input; specify if required)

INPUT CURRENT SUPPLIED BY COMPUTER

0.05A (+12V); 0.10A (−12V); 0.05A (−2V); 0.76A (+4.5V)

OPERATING CONDITIONS

(Limits imposed by paper tape)

Ambient temperature: 10° to 40°C (50° to 104°F)
Relative humidity: 20% to 80%

DIMENSIONS

HP 2752A: 33 inches (838 mm) high; 25-1/2 inches (648 mm) wide; 18-1/2 inches (470 mm) deep

HP 2754B: 33-1/2 inches (851 mm) high; 40 inches (1016 mm) wide; 24 inches (610 mm) deep

WEIGHT (WITH STAND)

HP 2752A:
Net weight: 77 lb (34,7 kg)
Shipping weight: 92 lb (41,8 kg)
HP 2754B:
Net weight: 225 lb (102 kg)
Shipping weight: 270 lb (123 kg)

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PLUG-IN 20 kHz ANALOG-TO-DIGITAL INTERFACE SUBSYSTEM

HP 91000A

HP 91000A PLUG-IN, 20 kHz ANALOG-DIGITAL INTERFACE SUBSYSTEM SPECIFICATIONS

NUMBER OF INPUTS		16 single-ended or 8 differential; jumper-selectable
RESOLUTION		12 bits, including sign; LSB = 5mV
FULL SCALE INPUT		+10.235V to −10.240V
THROUGHPUT RATE TO BUFFER[1]		To 20kHz, maximum, via Direct Memory Access (DMA)
SAMPLE & HOLD	Delay	150 nsec from trailing edge of pace pulse to "hold" strobe
	Aperture	< 250 ns total jitter with respect to external pace pulse
EXTERNAL PACE PULSE INPUT		+4.5V ± 0.5V, 1.5 ± 0.5μs pulse referenced to 0 ± 0.5V baseline, 100Ω source
OVERALL ACCURACY[1]	At 25° ± 5°C	±0.1% fs ± 1/2 LSB
	Temp. Coeff.	±0.004% fs/°C over 0° to 55°C range[2]
INPUT IMPEDANCE	Power On	> 5MΩ
	Power Off	1kΩ ±10%
MAXIMUM INPUT		±10.5V diff. + common mode, or high-to-computer chassis (S.E. inputs); ±10.24V high-to-common (S.E. inputs) for rated accuracy; up to ±15V, any input line to computer chassis, w/o damage.
INPUT PROTECTION		To ±15V, any input to computer chassis without damage.
SOURCE RESISTANCE		To 1kΩ, balanced or unbalanced.
CROSSTALK REJECTION		> 80dB, dc to 100Hz, using differential input
COMMON MODE REJECTION		> 80dB, dc to 100Hz, using differential input
COMPUTER I/O CHANNEL		One
INTERFACE CURRENT		2.4A (+4.5V), 0.05A (−2V) drawn from computer or I/O extender
MEMORY REQUIRED WORDS	In 9600A Series Systems	560 words for D.62 (non-DMA BCS driver) or 700 words for D.62A (DMA BCS driver) and 130 words for I2313 (FORTRAN/ALGOL interface).
	In 9600B/C/E Series Systems	440 words for RTE driver DVR62 and 370 words for R2313 (FORTRAN/ALGOL interface) or 600 words for RTE-B BASIC interface
OPERATING CONDITIONS		0° to 55°C (+32° to +131°F)[2], same as HP 2100 series Computers; up to 15°C (27°F) should be allowed for temperature rise inside HP system cabinets.
WEIGHT		Net: 4 lb. (1,8 kg). Shipping: 6 lb. (2,7 kg).
SYSTEM COMPATIBILITY		The plug in A-D Interface Subsystem is hardware and software compatible with all 9600 series Computer Systems for Data Acquisition and Control.

[1] *Absolute accuracy, including 3 sigma noise; linearity; offset; gain and dynamic response errors; ±10% line voltage variation. Includes multiplexer, sample-and-hold amplifier, and ADC.*

[2] *Temperature range outside of computer.*

SUMMARY OF PLUG-IN ANALOG-TO-DIGITAL INTERFACE SUBSYSTEM (May be ordered from 9600 series Computer Systems Configuring Guide)

HP 91000A Plug-In 20 kHz Analog-Digital Interface Subsystem, consisting of:

1. Analog-Digital Interface Card (91000-60001).
2. Mating Connector (02313-60010) for analog input.
3. Operation and Service Manual (91001-93001).
4. Verification routine (91000-60002).
5. Software driver and interface routine, supplied according to system in which HP 91000A A-D Subsystem will be used. See table of software options, at right.

HP 91000A-005

Single-Ended Input Cable, 16 foot (02313-60007), terminated with high-level multiplexer card mating connector at one end, unterminated at source end.

HP 91000A-006

Differential Input Cable, 16 foot (02313-60008), terminated with high-level multiplexer card connector at one end, unterminated at source end.

TABLE OF SOFTWARE OPTIONS

	For 9600 System in: A Series (BCS)	B Series (RTE-B)	C&E Series (RTE)
Order HP 91000A Software Option consisting of:	S30	S60	S50
DMA driver	D.62A	DVR62	DVR62
Non-DMA driver	D.62	n.a.	n.a.
Interface routine	I2313	*	R2313

**B series interface routine is included in RTE-B Library.*

HP 21-MX/65 DISComputer

The HP 21-MX/65 is a Disc Based System configured as a basic building block for the OEM. It consists of the HP 21-M/20 processor, HP 21-X/2 Semiconductor Memory, Dual-Channel Port Controller and 15 megabytes of moving head disc storage. Operating software and additional HP Data Systems products can be added to the 21-MX/65 to provide a specific system solution for the OEM.

System Specifications

PHYSICAL CHARACTERISTICS

M/20 Processor

Width: 42.55 cm (16-3/4 in.) behind rack mount.
48.3 cm (19 in.) front panel width on sides
Height: 22.23 cm (8-3/4 in.) in rack mount
Depth: 59.69 cm (23-1/2 in.).
58.42 cm (23 in.) behind rack mounting ears
Weight: 20.4 kg (45 lb)

7905A

Panel Height: 26.52 cm (10.44 in.)
Width: 48.03 cm (18.91 in.).
44.15 cm (17.38 in.) behind panel
Depth: 71.12 cm (28.00 in.),
68.10 cm (26.81 in.) behind panel
Weight: 73.5 kg (162 lb)

13037A

Panel Height: 13.34 cm (5.25 in.)
Width: 48.03 cm (18.91 in.),
42.55 cm (16.75 in.) behind panel
Depth: 57.63 cm (22.69 in.),
54.61 cm (21.55 in.) behind panel
Weight: 15.9 kg (35 lb)

POWER REQUIREMENTS

Processor

Input Line Voltage: 110 VAC @ ±20% (88 to 132 VAC)
220 VAC @ ±20% (176 to 264 VAC)
Input Line Frequency: 47 to 66 Hz
Power: 525 watts maximum

Disc Subsystem

100, 120, 220, 240V, all +5%, -10%
Single phase: 47 to 66 Hz

7905A

500 watts (1707 BTU) at 120V/60 Hz or 220V/50 Hz

13037A

175 watts (648 BTU) at 120V/60 Hz
200 watts (683 BTU) at 220V/50 Hz

SECTION B. FLIGHT SOFTWARE SUPPORT SYSTEM

Experiment flight software is a heirarchy of sets of logical instructions that operate upon *data* to perform some function or service. See Figure B-1. The total software within the computer is the operating system, which is machine-configuration-dependent. It is comprised of three parts that are considered as *overhead*. One part relates to the device management, both internally (CPU, I/O) and externally (tape or disc, displays, etc.). This software would identify each device by an address so that it may be called into operation when needed. A second part relates to the data management--particularly the storage, retrieval and flow control of data within the internal (working) memory of the computer. The third part is the executive, which determines what and when the computer system components will be activated. Included in the executive is a task scheduler to identify when selected operations are to occur--that is, which application program is to be executed.

An application program is task-specific and consists of an assembly of library routines linked to specified parameters called *initialization data*. Library routines are a fixed sequence of operations, and are that part of the software which do the actual work. Several library routines may be linked together by the application program, and to the parameters that control their use. An example of initialization data (in a tutorial mode) was given in Section 6.0 (Figure 6.0-2).

Of this heirarchy, which applies to all software systems, only the application program, the data modules, and the executive task scheduler are application-specific. The operating system, software support system, and library routines are developed once and are considered to be part of the startup activities.

The library routine size was estimated in terms of the number of FORTRAN or equivalent high-order language statements needed to define the routine. This approach was chosen rather than the use of machine words, because this is how the programmer would estimate his work. These estimates are based upon Rockwell experience with similar routines developed for both large central systems (IBM S/370) and mini-computer systems. As shown in Table B-1, they range in size from 10 to 2500 statements.

The FSSS is the tool by which all the other standard in-flight software is developed. It is itself *software* and has the elements shown in Figure B-2. The development of this software is separated into the following phases: system definition, source code editor, file management, checkout, documentation, input/output processing, and tutorial.

The *system definition* includes but is not limited to the overall system analysis, the development of any overall system design, and any necessary modifications of an existing operating system. The system definition also includes the definition of the programming language and the programming manual as well as the procedures needed to define, check out and control the development of all software. Each computer type selected would need its own compiler and assember and troubleshooting tools, although some of the library routines may be common.

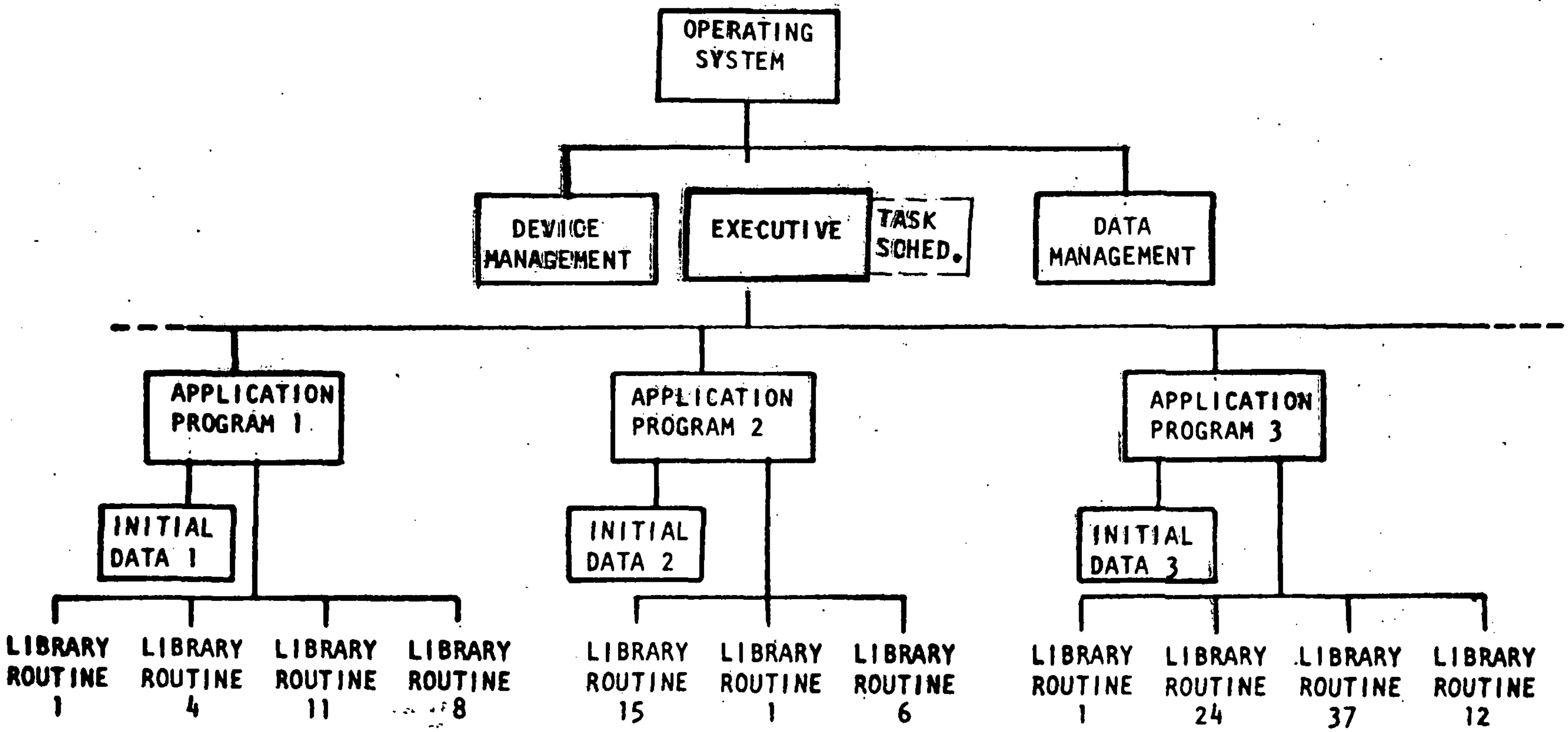

Figure B-1. Experiment Flight Software

Table B-1. Library Sizing Estimates

Routine	FORTRAN Statement	Routine	FORTRAN Statement
Data acquisition	100	Autocorrelation	20
Data annotation	50	Display generation	500
Telemetry/record formatting	100+	Command generation	200
Recorder control	50+	Sensor/platform pointing control	150+
Display formatting	50	Caution and warning backup	50
Scientific data control	150	Schedule sequence	150
Operations status	25+	Quick-look analysis	150
Limit checks	25	Trend analysis	150
Data compaction	50+	Data compression	100
Image signature analysis	50	Coordinate transform	10
Non-image signature analysis	35	Fourier analysis	313
Graphic processing	500	Zero-order prediction	50
Image processing	2500	Matrix analysis	500

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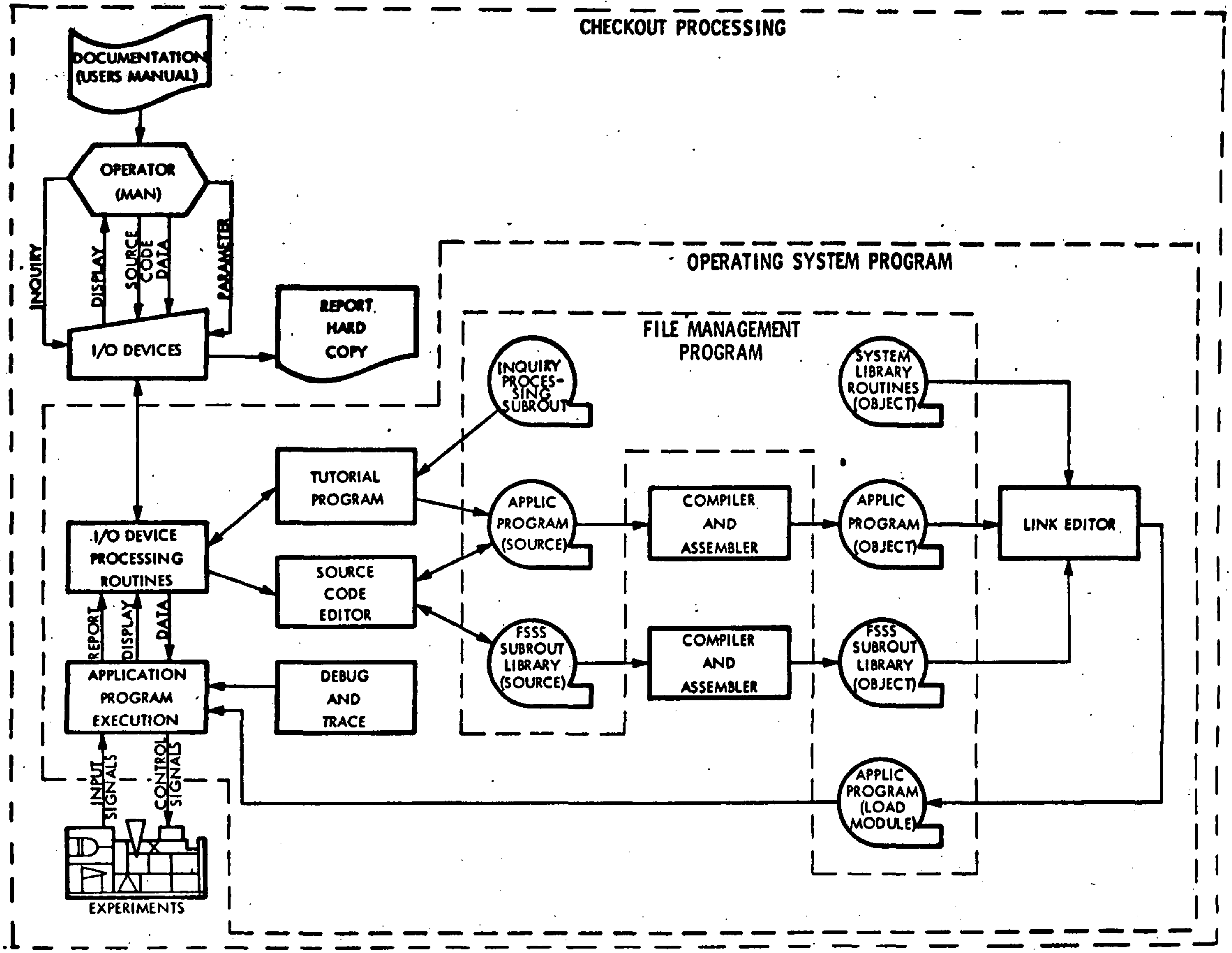

Figure B-2. Flight Software Support System

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The *source code editor* function includes but is not limited to the modification of an existing source code editor or the development of a source code editor in the absence of an existing one. The function of the source code editor is to provide a means to revise selected source code sets.

The *file management* function includes but is not limited to the modification or development of the maintenance routines using a dual cassette recording system. This phase also includes the core storage allocation routines.

The *checkout* function includes but is not limited to the testing of the integrated system by using simulated as well as actual inputs. Individual subsystem tests are performed as part of the individual phases.

The *documentation* function includes but is not limited to the development of an experimenter's operating handbook to aid in the production of the experiment applications software programs. Individual subsystem and overall system detailed functional documentation is performed as part of the individual phases.

The *input/output* device *processing routines* are routines that interface between the man using the input/output device and the FSSS. The communications between the man as an operator and the system as a program is through the use of a near-English, interactive/query language. The input/output device processing routines accept queries and responses between the operator and the program. These queries and responses are in the form of measurement description data, application processing description data, and other data as needed.

The function of the *tutorial* program is to process, on an iterative basis, messages to/from the operator in order to aid in the on-line production of application programs. The tutorial program queries the operator as to his algorithmic requirements and accepts responses from the operator. It analyzes the responses for syntactical structure and semantical form. It produces the required action and returns to the operator the results, or queries the operator for further information. The ultimate result of the tutorial process is the production of an application program generated according to the operator's requirements and its execution for checkout purposes.

Upon initiation, the tutorial program exchanges general information with the operator. As more detailed information concerning a particular application is needed, the tutorial program utilizes specialized algorithm processing subroutines to process the detailed tutorial language. The specialized algorithm subroutine queries the operator for the details of the algorithm. It analyzes the responses and, for the analysis, it generates the source language for an application program that is tailored to the specific algorithm. It does this by referencing particular routines from the FSSS library file. The tutorial program then transfers control to the program-compiling process.

The function of the *compiler* and the *assembler* is to translate the source version of the application program in high-order language form into machine language. The function of the *link editor* is to supplement the application program with mathematical and operational service routines. It also adds those FSSS library routines that have been referenced in the application program. It then produces a logically organized load module suitable for execution. Table B-2 describes the library routines that have been identified.

Table B-2. Library Routines

DATA ACQUISITION	
FUNCTION	Data must be transferred from some external source to the computer for processing. Information can be transferred periodically by sampling or, randomly, by polling or interrupting. All data, however will have a source identification, a specific location in computer memory, and a byte or bit length transfer count. Parity or cyclic count can be included to reduce errors. Information is transferred from a selected device to the computer by a simple FORTRAN call. The routine will have the capability of moving data in both byte or burst mode, transfer on "data ready" and error handling and recovery. This routine will require coding at the assembler level.
REQUIREMENTS	Data transfer (device address, memory location, byte count), interrupt handling, and error handling and recovery.
DISPLAY FORMATTING	
FUNCTION	Page skeleton and sub-page skeleton tables will contain predefined text and position information. Entries will be selected using a table-lookup routine and vector list. Numerical data from either computer memory or external source will be converted to text and merged with the skeleton. Regeneration capability will be provided to update dynamic data.
REQUIREMENTS	Page skeleton (text and position table, entry vector list), data merge (numerical conversion, text transfer), data output and screen generation, and error handling and recovery.
CAUTION AND WARNING	
FUNCTION	Data from critical areas are periodically polled and checked for out-of-range values. Areas of high criticality will cause an immediate interrupt. An attention device will be triggered and the appropriate message displayed on the graphic device.
REQUIREMENTS	Interrupt and poll, table search, and message display.
COMMAND GENERATION	
FUNCTION	Individual commands are processed by a command interpreter which decodes the command syntax, assembles the proper bit pattern, and provides time data if required. The command group is checked for validity and errors, and a sum check word is added if required.
REQUIREMENTS	Command interpreter, operation list pointer, sum check, error and recovery.
DATA ANNOTATION	
FUNCTION	Entries will be selected using a table-lookup routine and vector list. A sub-identifier will be combined with the selected entry to provide exact definition. Entries are open-ended and contain a length attribute.
REQUIREMENTS	Description table, entry vector list, sub-identification, length
DISPLAY GENERATION	
FUNCTION	This routine will generate orders and data to display alphanumeric characters, plot points, draw vectors, draw grids (Cartesian and polar coordinates, linear or logarithmic), grid labels, and circles and arcs (line segment approx.).
REQUIREMENTS	Text and vector
GRAPHIC PROCESSING	
FUNCTION	Graphic information is stored in two distinct formats--text and vector. Display skeletons are stored in tables with entry location pointers. A display may be stored completely, partially, or created dynamically. Interactive communication between experimenter and computer is obtained by both graphic display and keyboard entry. Commands and subcommands are entered on the keyboard and decoded by table lookup.
REQUIREMENTS	Keyboard entry (text, numeric conversion, menu selection, interrupt handling) and display [skeleton table, plotting routine, numeric conversion, analysis (interactive)].

Table B-2. Library Routines (Cont.)

LIMIT CHECK	
FUNCTION	Maximum and minimum values are selected from a range table using a vector list. A comparison is made and the proper condition code set or message generated.
REQUIREMENTS	Range table (vector list and message pointer) and message display
TELEMETRY FORMATTING	
FUNCTION	A telemetering data address table contains pointers to specific data to be sampled and merged. The output buffers are used to alternately store the information prior to transmission. This routine will provide commutation, sub-commutation and multiplex capability.
REQUIREMENTS	Sequencer (clock interrupt, data selector) and buffer control (datum vector, buffer switch, dropout control)
RECORDING FORMATTING	
FUNCTION	A recording data address table contains pointers to specific data to be sampled and merged. Two output buffers are used to alternately store the information prior to transmission. This routine will provide commutation, sub-commutation and multiplex capability.
REQUIREMENTS	Start-stop, record playback, and error handling and recovery
RECORDER CONTROL	
FUNCTION	This routine will generate commands to start recorder, stop recorder, and rewind.
REQUIREMENTS	Status information will be made available to indicate tape stop, tape running, tape at start, tape ended, and error condition.
SCIENTIFIC DATA CONTROL	
FUNCTION	A sequencer will operate under a clock interrupt to drive a task selector. The task selector, using a vector pointer and command table will provide predefined commands that are placed in the time-depended queue and interrupt list. Commands will be executed as a function of time or in response to an interrupt.
REQUIREMENTS	Sequencer (clock interrupt, task selector), task controller (task table, vector list), and perform operations (execute command list, iterate feedback loop, limit-check conformation)
OPERATION STATUS	
FUNCTION	The current operation list is read from the schedule sequencer to obtain the active status message skeleton vector and device addresses. The status work from each identified device is read and decoded. Numerical conversions to text format are performed, if required. Device status information is combined with numerical data and status skeleton to form the complete status message. System configuration is validated.
REQUIREMENTS	Status definition table (address vector, status bit mask), condition message table, message assembler, message display, and configuration validation.
SCHEDULE AND SEQUENCE	
FUNCTION	An operation sequence table is maintained to control all experiments on a time-share basis. Individual time-dependent operations are placed in an execution queue tied to the master clock.
REQUIREMENTS	Sequence table, clock, command output, and error and recovery
SENSOR POINTING	
FUNCTION	Sensor commands will be generated to provide slew, track, and calibrate capability. Feedback of sensor position will be processed on a periodic basis to ensure accurate tracking.
REQUIREMENTS	Interrupt (clock, drift), command (slew, track, calibrate) and feedback

Table B-2. Library Routines (Cont.)

PLATFORM CONTROL	
FUNCTION	Feedback data will be processed on an interrupt basis to maintain platform positioning. Correction information will be sent to the appropriate servos.
REQUIREMENTS	Alignment, track and drift, and calibrate
QUICK-LOOK ANALYSIS	
FUNCTION	Quick-look storage buffers containing a preselected group of data elements are continuously updated. A quick-look request will provide single elements or arrays in engineering units.
REQUIREMENTS	Data location table, numeric conversion, and display
IMAGE SIGNATURE ANALYSIS	
FUNCTION	A two-dimensional Fourier analysis is performed on the image to provide the required signature. The Cooley-Tukey algorithm is used.
REQUIREMENTS	Two-dimensional Fourier analysis
IMAGE PROCESSING	
FUNCTION	Image processing is divided into three main areas--image coding, image restorage and enhancement, and image data extraction. Image coding is performed to represent a digital picture with as few number of code bits as possible. Reducing the number of code bits permits (1) reduced image storage requirements, and (2) individual images to be transmitted faster. Techniques include quantitization reduction, statistical coding, predictive coding and transform coding. The second area is concerned with improving the quality of images. The restoration problem is to take a poor quality image and try to make it as good as it should have been if it had had no degradation. Image enhancement operations are more concerned with subjective viewing--making images appear better to the human viewer. The third area is concerned with extraction of data from images; these data may be in the form of lines, curves, patterns, or objects.
REQUIREMENTS	Image coding [bit rate reduction (transmit faster, transmit more)], image restoration and enhancement (de-focus, linear motion, simple aberration, noise, turbulent atmosphere, contract enhancement), and image data extraction (line and curve detection, pattern recognition, object identification and classification)
NON-IMAGE SIGNATURE ANALYSIS	
FUNCTION	A one-dimensional Fourier Analysis is performed on the image to provide the required signature. The Cooley-Tukey algorithm is used.
REQUIREMENTS	Fourier Analysis
FOURIER ANALYSIS	
FUNCTION	The Fourier Analysis is performed using the Cooley-Tukey algorithm. One-, two-, or three-dimensional arrays can be analyzed.
REQUIREMENTS	Cooley-Tukey algorithm (fast Fourier transform)
MATRIX ANALYSIS	
FUNCTION	These routines will provide capability to add, subtract, product, transpose, invert.
REQUIREMENTS	Mathematical computations.
TREND ANALYSIS	
FUNCTION	Trend analysis routines will provide autocorrelation, regression, test run and test trend.
REQUIREMENTS	Autocorrelation, regression, test run, and test trend.

Table B-2. Library Routines (Cont.)

DATA COMPRESSION	
FUNCTION	Domain quantitization is used to provide maximum data range with minimum signal degradation. Two models are provided--linear quantitization in which the quantum levels are spaced over some maximum range; and Gaussian, where the quantitization levels are chosen to partitiion the Gaussian curve into equal areas.
REQUIREMENTS	Domain quantitization (level selection and quantitization level
DATA COMPACTION	
FUNCTION	Data compaction methods, to a great extent, are a function of the properties of the way the data can vary. Techniques are employed to provide maximum compaction with a minimum loss of resolution. Quantitization reduction is used where high-frequency loss is acceptable. Statistical coding is used where a large amount of redundancy is present. Transform coding using Fourier, Hadamard, or cosine functions can be used where limited frequency information is known.
REQUIREMENTS	Quantitization reduction, statistical coding, and transform coding (fast Fourier transform, Hadamard, cosine functions)
ZERO-ORDER PREDICTION	
FUNCTION	Each sample of the scanned signal is sequentially subtracted from its predicted value and the difference quantitized and coded. This quantitized difference is the basis of the prediction of the next value.
REQUIREMENTS	Quantitized difference of each scanned signal.
COORDINATE TRANSFORM	
FUNCTION / REQUIREMENTS	Coordinate transform requires the product of a matrix and vector; this routine will also transpose the matrix for a reverse transform. $$\begin{vmatrix} \text{Matrix} \end{vmatrix} \cdot \begin{vmatrix} V_1 \\ V_2 \\ V_3 \end{vmatrix} = \begin{vmatrix} V_{B1} \\ V_{B2} \\ V_{B3} \end{vmatrix}$$ $$\begin{vmatrix} \text{Matrix} \end{vmatrix}^T \cdot \begin{vmatrix} V_{B1} \\ V_{B2} \\ V_{B3} \end{vmatrix} = \begin{vmatrix} V_1 \\ V_2 \\ V_3 \end{vmatrix}$$
AUTOCORRELATION	
FUNCTION	*This subroutine calculates the autocovariances for a given time series.* $$R_j = \frac{1}{n-j+1} \sum_{i=1}^{n-j+1} (A_i - \text{Aver})\,(A_{i+j-1} - \text{Aver})$$ Where Aver = $\frac{1}{m} \sum_{i=1}^{n} A_i$

SECTION C. GROUND SOFTWARE SUPPORT SYSTEM

The ground software support system is the tool by which the user can call and initialize application programs. It is itself software and has the elements shown in Figure 6.0-3. Initialization is tutorial and execution is immediate, with results in the form of printout, trace, etc., as appropriate.

The library of ground processing programs that have been identified are described in the following *process data sheets*, covering 29 essential programs. The WBS numbers that are noted on the data sheets are those assigned to specific tasks identified in the basic SUIAS effort.

CODE

TITLE: Experiment Groupings

FUNCTION/PROCESS:

Develop candidate experiment groups sized to Orbiter/Spacelab capabilities. Consider basic priorities, experiment compatibilities, ATL configuration options, and mission resources.

INPUTS:

Experiment definitions--configuration and operations
Experiment priority criteria

OUTPUTS:

Preliminary definitions of candidate experiment groups

APPLIES TO:

WBS 10-30-	Advance Experiment/Mission Definition
WBS 30-10-	Mission Requirements

CODE

TITLE: System/Program Cost Analysis

FUNCTION/PROCESS:

Establish a system/program cost model.

Conduct cost-related trade studies to assure the most effective use of program resources. Particularly, investigate the interrelationships among funding profile, experiment grouping, and ATL configuration options.

INPUTS:

Experiment configuration descriptions

Experiment development plans/schedules

OUTPUTS:

System/program cost and funding data

APPLIES TO WBS:

10-20-	Cost and Performance Management
10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements

CODE

TITLE: Ground Trace Generator

FUNCTION/PROCESS:

Perform trajectory/orbit calculations and generate ground trace plots on suitable maps with timing "pips" to illustrate trajectory overflight/proximity to land masses and specified targets.

INPUTS:

Boost trajectories
Entry trajectories
Orbit characteristics and initial conditions

OUTPUTS:

Ground trace plots for all flight phases

APPLIES TO WBS:

30-10-	Mission Requirements
30-20-	Mission Analysis
30-30-	Operations Plans
30-40-	Mission Reports
30-10-	Mission Control
50-10-	System Requirements

CODE

TITLE: Target Opportunity Generator

FUNCTION/PROCESS:

Generate target encounter and access data for various candidate orbits and initial conditions.

INPUTS:

Candidate orbits and initial conditions
Specified target locations (terrestrial and/or celestial)
Target viewing constraints

OUTPUTS:

Target encounter sequences (rise-set times)
Target access summaries
- Number of encounters (by target location)
- Cume viewing time

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-30-	Operations Plans

CODE

TITLE: Communications Coverage

FUNCTION/PROCESS:

Generate line-of-sight access data between the Orbiter/Spacelab and various system communications elements. Consider variations in orbit characteristics along with different communication satellite locations.

INPUTS:

Candidate orbits and initial conditions

Specified MSFN ground terminals and their locations

TDRS locations (geosynchronous orbit)

DOMSAT locations (geosynchronous orbit)

OUTPUTS:

Line-of-sight access characteristics

Rise-set times

Line-of-sight distance and rate

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements

CODE

TITLE: Solar/Mission Geometry

FUNCTION/PROCESS:

Generate sun angles (line of sight) with respect to target directions and communication line(s) of sight. Determine sun rise and set times (occultation histories) and surface lighting (local time) alone the orbit ground trace. Consider variations in orbit characteristics and initial conditions.

INPUTS:

Candidate orbits and initial conditions
Specified target locations
Specified communication satellite locations

OUTPUTS:

Sun-angle histories
Surface lighting conditions

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
50-10-	System Requirements and Analysis

CODE

TITLE: Radiation Environment

FUNCTION/PROCESS:

Determine expected radiation environment as a function of orbit characteristics and mission duration.

INPUTS:

Candidate orbit characteristics and initial conditions
Candidate mission dates

OUTPUTS:

Radiation environment characteristics

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis

CODE

TITLE: Orbit Contamination

FUNCTION/PROCESS:

Establish a general Orbiter/Spacelab contamination model (includes water dump, RCS exhaust, cabin/module leakage). Further develop outgassing characteristics of experiments and supporting equipment. Determine contamination levels for various missions/configurations and evaluate the acceptability to the experiment operations.

INPUTS:

Candidate orbit characteristics
Experiment configuration descriptions
Subsystems/experiment usage profiles

OUTPUTS:

Contamination characteristics as a function of mission phase
Contamination impact evaluations

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Atmosphere Model(s)

FUNCTION/PROCESS:

Establish atmosphere model(s) to determine the effects of the atmospheric environment on experiment operations. This includes signal attenuation characteristics and special weather phenomena as appropriate. Evaluate atmospheric effects on mission characteristics and constraints for various experiment/orbit combinations.

INPUTS:

Candidate orbit characteristics
Experiment definitions

OUTPUTS:

Mission and/or operational constraints due to atmospheric phenomena

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definitions
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Orbit Decay

FUNCTION/PROCESS:

Combine configuration characteristics with model atmosphere(s) to determine orbit decay and related parameters. Generate decay profiles, acceleration environments and orbit make-up delta-V requirements as functions of orbit parameters and configuration variables.

INPUTS:

Orbiter aerodynamic characteristics
Orbiter/Spacelab configuration and mass properties
Orbiter orientation history
Candidate orbit characteristics

OUTPUTS:

Orbit decay profiles (h vs. time)
Acceleration environment
Orbit make-up delta-V requirements

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Orbit Maneuvers

FUNCTION/PROCESS:

Analyze orbital maneuvering requirements to meet experiment needs, e.g., change altitude, rendezvous, orbit makeup , and control orbit ground trace. Determine the location, timing, pointing and powered flight parameter histories for the required maneuvers.

INPUTS:

Experiment orbit and target geometry requirements
Oriber/Spacelab configuration and mass properties
Orbiter propulsion subsystem characteristics

OUTPUTS:

Orbit maneuver requirements in terms of
- Delta-V
- Location
- Time

Powered flight histories
- Acceleration
- Thrust pointing
- Velocity
- Distance

Propellant requirements

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis

CODE

TITLE: Orbit Error Analysis

FUNCTION/PROCESS:

Perform orbit error analyses to determine the interactions between orbit update mechanization, update frequency and experiment support requirements. Consider MSFN tracking, TDRS tracking and on-board (autonomous) concepts. Establish orbit update requirements to support experiment operations.

INPUTS:

Error sources and magnitudes for each navigation concept
Experiment definitions and ephemeris sensitivities

OUTPUTS:

Orbit update requirements
Experiment support requirements

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Subsatellite Motion Analysis

FUNCTION/PROCESS:

Establish a subsatellite relative motion model (relative to the Orbiter/Spacelab). Analyze relative motion characteristics as functions of configuration and orbit conditions. Determine stationkeeping requirements and line-of-sight envelopes.

INPUTS:

Subsatellite configuration characteristics and mass properties
Orbiter/Spacelab (mission-equipped) characteristics and mass properties
Candidate orbit characteristics
Subsatellite experiment definitions

OUTPUTS:

Subsatellite relative motion histories
Subsatellite line-of-sight envelopes
Stationkeeping requirements, delta-V's and frequencies

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis

CODE

TITLE: Mission Consumables

FUNCTION/PROCESS

Develop a consumables model for all mission consumables including special experiment fluids, gases, etc. Consider consumption rates for various usage modes and the interrelationships between cryo usage for electrical, power and water available for crew use and supplemental cooling. Generate consumables profiles for candidate missions and determine water dump intervals and other crew operations involving consumables management.

Overall consumables include the following:

Electrical power (Cryo, H_2, O_2)
RCS propellant
Water } related waste management
Food }
O_2 - N_2
LiOH

INPUTS:

Orbiter/Spacelab subsystems characteristics and operational modes
Experiment definitions, equipment characteristics and operational modes
Candidate mission profiles and operational sequences

OUTPUTS:

Consumables profiles
Mission loading requirements
Consumables management options

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Orbiter Attitude Management

FUNCTION/PROCESS:

Establish coordinate transformations relating Orbiter orientation to various coordinate systems. The various coordinate systems include celestial (equatorial) inertial, galactic plane inertial, orbital plane inertial and the local attitude reference system. For candidate missions and their related orbit geometries determine the sun line-of-sight angles in Orbiter body coordinates. Also, determine communication line-of-sight angles in body coordinates and investigate Orbiter attitude envelopes which are within the antenna limits (for both single and dual antenna installations). Communication links include TDRS, MSFN, ground truth/target sites, and subsatellites.

INPUTS:

Candidate orbit characteristics
Candidate target location/directions
Payload/experiment configuration characteristics

OUTPUTS:

Orbiter pointing envelopes/limits
Orbiter attitude sequences
Pointing constraints/impacts on orbit geometry

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Instrument Pointing

FUNCTION/PROCESS:

Establish coordinate transformations relating instrument pointing directions to the Orbiter body coordinate system. Based on candidate targets and mission geometries, determine instrument pointing angles with respect to Orbiter body coordinates. Consider basic azimuth/elevation angles as well as gimbal angles for appropriate instrument pointing systems, e.g., IPS, SIPS, TIPS, etc. Conduct iterations with various sensor installations, Orbiter attitudes and orbit geometries to determine preferred installation geometries and operations.

INPUTS:

Candidate orbit characteristics
Candidate target locations/directions
Payload/experiment configuration characteristics
Experiment installation characteristics

OUTPUTS:

Orbiter pointing envelopes/limits
Gimbal angles for instrument pointing

APPLIES TO WBS:

30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis

CODE

TITLE: Mission Timeline Generation

FUNCTION/PROCESS:

Based on target opportunities and related trajectory parameters, construct mission timelines depicting both crew and experiment operations. Consider variations in operational modes for each experiment and the time sharing of mission resources (crew availability, electrical power, precision pointing, etc.). Integrate experiment operations with Orbiter and Spacelab operations.

INPUTS:

Candidate mission geometries, target opportunities and trajectory events
Flight crew definitions
Crew task scheduling criteria
Experiment definitions and operational characteristics and procedures
Orbiter operational guidelines and constraints
Spacelab operational guidelines and constraints

OUTPUTS:

Mission timelines
Integrated mission timelines

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-30-	Operations Plans
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Experiment Data Processing

FUNCTION/PROCESS:

Perform real-time or near-real-time experiment data processing as an aid to mission control. Based on the processed data, determine data adequacy and quality and determine the need for experiment equipment adjustment and/or procedural changes.

INPUTS:

Experiment definitions, configurations, operations and output data format
Expected data characteristics

OUTPUTS:

Confirmation of data adequacy/quality
Experiment control adjustments
Experiment operational procedure changes

APPLIES TO WBS:

40-10-	Mission Control
40-20-	Monitoring
40-30-	Science Coordination and Ground Support

CODE

TITLE: Orbit Ephemeris/Timeline Update

FUNCTION/PROCESS:

Update mission timelines based on orbit ephemeris updates from Orbiter mission control. Determine new target acquisition times and other trajectory events to which experiment operations are indexed. Generate updated timelines for use in experiment mission control operations.

INPUTS:

Baseline (planned) mission timelines
Orbit ephemeris/state vector updates

OUTPUTS:

Updated mission timeline segments

APPLIES TO WBS:

30-40-	Mission Reports
40-10-	Mission Control
40-30-	Science Coordination and Ground Support

CODE

TITLE: Contingency Operations Planning

FUNCTION/PROCESS:

Based on experiment and Spacelab subsystems definitions, identify potential degraded operational modes (for each experiment and/or subsystem) and their general procedures. Establish experiment data priorities for use in "contingency" mission timelines. In cases of actual experiment failures and/or degraded functions during a flight, construct modified mission timelines to best utilize the available resources in the presence of degraded operations. Consider both experiment priorities and mission opportunities for remaining experiments (in the event of a failure).

INPUTS:

Experiment definitions
Spacelab/payload subsystems definitions (flight configurations)

OUTPUTS:

Contingency mission plans
Modified mission timelines

APPLIES TO WBS:

30-20-	Mission Analysis
30-30-	Operations Plans
30-40-	Mission Reports
40-10-	Mission Control
40-30-	Science Coordination and Ground Support

CODE

TITLE: Subsystems Performance Monitor

FUNCTION/PROCESS:

Monitor subsystems performance during mission operations. Consider special equipment and/or operations which might be required to meet experiment needs for some payloads. Accumulate histories of subsystems performance for updateing real-time ground monitoring requirements.

INPUTS:

Payload/experiment definitions (flight configurations)
Baseline mission operations and timelines

OUTPUTS:

Verification of subsystems operations/performance
Identification of subsystems operational/performance anomalies and descriptions of their characteristics
Subsystems performance histories
Subsystems (between flight) servicing recommendations

APPLIES TO WBS:

40-20- Monitoring

CODE

TITLE: Ground Truth Coordination and Control

FUNCTION/PROCESS:

Monitor real-time ground truth/target site operations in support of overall mission operations. Coordinate timeline updates with ground site operations and monitor the flow of supplemental ground truth data into the mission data bank.

INPUTS:

Baseline ground site operations
Orbit ephemeris/timeline updates
Contingency operations/sequencies (timeline modifications)

OUTPUTS:

Coordinated ground site/flight operations
Integrated flight and ground site data (into the mission data bank)

APPLIES TO WBS:

40-20-	Monitoring
40-30-	Science Coordination and Ground Support

CODE

TITLE: Payload (Experiments) Status Monitor

FUNCTION/PROCESS:

Monitor experiment operational readiness functions in support of mission operations. Verify launch readiness, system ready for activation in orbit, system ready for deorbit, etc.

INPUTS:

Baseline mission operations
System/experiment status data
System readiness criteria

OUTPUTS:

Confirm operational readiness at appropriate mission mode change events

APPLIES TO WBS:

40-10-	Mission Control
40-20-	Monitoring

CODE

TITLE: Thermal Analysis

FUNCTION/PROCESS:

Based on simplified thermal models, analyze thermal characteristics of candidate payloads and mission profiles. Determine temperature histories for critical components and overall heat rejection characteristics. Correlate heat transfer/rejection requirements with mission geometries.

INPUTS:

Payload/experiment definitions
Candidate orbit characteristics
Candidate Orbiter attitude histories
Candidate mission timelines

OUTPUTS:

Parametric thermal characteristics data
Temperature control subsystem requirements

APPLIES TO:

30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis

CODE

TITLE: Mass Properties Model and Analysis

FUNCTION/PROCESS

Formulate a mass properties model for the Orbiter/Spacelab. Include variations in crew size, mission duration and Spacelab/payload configurations. Provide the capability to determine gross liftoff weight, abort landing weight and normal landing weight as functions of the above variables. Mass properties include weight, c.g., moments of inertia including cross-products. Based upon this mass properties model, determine mass properties for candidate payloads and mission configurations.

INPUTS:

Orbiter mass properties including "payload" chargeable items
Spacelab mass properties
Candidate payload/experiment configurations
Mission consumables requirements

OUTPUTS:

Mass properties model
Mass properties for candidate payloads and missions

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Loads/Stress Analysis

FUNCTION/PROCESS:

Perform loads and stress analyses for candidate experiment installation configurations. Establish structural requirements which meet the Orbiter/Spacelab loads criteria.

INPUTS:

Experiment definitions
Candidate experiment installation configurations
Orbiter/Spacelab loads criteria

OUTPUTS:

Structural requirements for experiment and related equipment installation

APPLIES TO WBS:

50-10- System Requirements and Analysis

CODE

TITLE: Electrical Power Analysis and Requirements

FUNCTION/PROCESS:

Determine electrical power and energy requirements for candidate payloads and missions. Analyze special power distribution and power conditioning needs for specific experiments (if required). Analyze peak power and total energy characteristics with variations in mission operations and timelines and their potential impacts on heat rejection loads. Compare payload power/energy needs with the standard Orbiter/Spacelab interface and identify support deltas. General parametric cryo consumption data as functions of mission/operations and establish overall cryo requirements for each candidate mission.

INPUTS:

Candidate payload/experiment definitions
Candidate mission profiles and timelines
Standard Orbiter/Spacelab electrical power provision/interfaces

OUTPUTS:

Electrical power profile
Parametric cryo consumption data
Delta electrical power requirements
Mission cryo loading requirements

APPLIES TO WBS:

10-30-	Advance Experiment/Mission Definition
30-10-	Mission Requirements
30-20-	Mission Analysis
30-40-	Mission Reports
50-10-	System Requirements and Analysis

CODE

TITLE: Data Management Analysis

FUNCTION/PROCESS:

Analyze the data output characteristics for candidate payloads to determine mission data management requirements. Based upon candidate missions/experiment operations, determine data output characteristics (data type, rates). Consider both subsystem and experiments and command and control as well as experiment data flow. Establish control and display requirements. Based upon candidate missions/operations and real-time data transmission capability, determine the on-board data storage requirements. Consider the interfaces with mission control and PI participation in experiment operations.

INPUTS:

Candidate payload/experiment definitions
Candidate mission profiles and timelines
Orbiter/Spacelab data management provisions/interfaces

OUTPUTS:

Payload controls and displays requirements
Experiment data output profiles
Payload data storage requirements

APPLIES TO WBS:

30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis

CODE

TITLE: Stabilization and Control Analysis

FUNCTION/PROCESS:

Synthesize a disturbance torque model depicting variations in Orbiter/Spacelab-experiment payload configurations and orbit characteristics. Develop a compatible RCS consumption model which will permit the analysis of various stabilization concepts. These include: variations in jet logic for different deadband dynamics, supplemental cold gas concepts, CMG configurations, reaction wheels, and magnetic torquing. Based upon the mass properties of candidate payload configurations and mission timelines, generate parametric RCS consumption data as functions of mission and configuration characteristics. Establish stabilization and control subsystem requirements and RCS loading requirements.

INPUTS:

Candidate payload/experiment definitions
Mass properties for candidate Orbiter/payload configurations
Candidate mission/operations profiles

OUTPUTS:

Disturbance torque model
RCS consumption model
Parametric RCS consumption data
Stabilization and control subsystem requirements
RCS mission loading requirements

APPLIES TO WBS:

30-10-	Mission Requirements
30-20-	Mission Analysis
50-10-	System Requirements and Analysis